THE NINEVAH MISSION: A DESIGN SUMMARY FOR AN UNMANNED MISSION TO VENUS

Volume 1

A design project by students in the Department of Aerospace Engineering at Auburn University, Auburn, Alabama, under the sponsorship of NASA/USRA Advanced Design Program.

Auburn University
Auburn, Alabama
June, 1988

Contributions:

Wayne Ayer	Propulsion Cytherean Background Lander Environmental Control
John Blue	Trajectories
Jack Chapman	Instrumentation Structures Lander Configuration
Brook Smith	Communications Power Sources and Requirements Technical Drawings

ABSTRACT

This report contains the design summary for the Ninevah Mission, an unmanned mission to Venus. The design includes a Hohmann transfer trajectory analysis, propulsion trade study, an overview of the communication and instrumentation systems, power requirements, probe and lander analysis, and finally a weight and cost analysis.

TABLE OF CONTENTS

LIST OF FIGURES

PROJECT SUMMARY

Previous American and Soviet unmanned missions to the surface of Venus have proved to be invaluable in the study of the solar system's planets in that these missions have offered planetary scientists an opportunity to examine in more detail the theories of comparative planetology. These previous missions included multiprobe landers that have shown the extremely harsh conditions which exist in the Cytherean* atmosphere and on the planet's surface. Because of such conditions, these lander probes have all had relatively short data transmission times. The most recent American exploration of Venus, the Pioneer Venus 2, a multiprobe, arrived December 9, 1978, and transmitted somewhat conclusive data for sixty minutes. With the successful arrival of this mission, much has been learned as to how a longer-lasting, more conclusive mission can be attained.

This report describes a mission that would survive approximately three times longer than any previous mission and includes a task that has never been attempted before: atmospheric balloon probes that will take high-resolution aerial photographs of the Cytherean surface. This mission will increase the quantity as well as the quality of the information concerning the conditions which exist on Venus.

---

*While the term Venusian is an adjective used in referring to Venus, the term Cytherean, from greek mythology, is the more commonly used adjective. Venusian is considered to be awkward, thus in this report, Cytherean will be used in describing Venus.

Using existing technology in communications, energy systems, and materials sciences, this mission will provide more information on Venus' atmosphere and surface. The objectives of this report are to technically design and develop a successful mission with emphasis on the most critical areas of the mission including trajectory, propulsion, instrumentation, communication, power requirements and sources, structures, and how all of these systems are integrated to yield such a successful mission.

INTRODUCTION

After taking all other missions to Venus into account, American scientists still have many unanswered questions. The Soviets have provided results of their missions to Venus; however, the reliability and accuracy of the data is questionable. But, perhaps with some knowledge of our combined successes and failures, American scientists can execute a more comprehensive Cytherean mission.

In-depth research has been done and an optimum configuration has been decided upon. The configuration (Figure 1) is as follows:

1. One combination bus/orbiter to transport one lander and three probes along with all instrumentation from an earth orbit to a near polar Cytherean orbit.
2. One large lander with a robotic arm and imaging system.
3. Three small balloon probes each carrying a high resolution imaging system.

Unlike the Pioneer Venus program, which consisted of a separate bus and orbiter, the Ninevah mission is composed of a single orbiter/bus which uses a buffered memory during occultation (time spent out of earth's line-of-sight). In addition, communications with the lander and probes, to be located on the near side of Venus, will be direct since the Deep Space Network is capable of transmitting high and receiving extremely low communication power outputs. The major events of the Ninevah mission are profiled in both Figures 2a. and 2b.

Analysis of previous Soviet and American missions to Venus indicated a strong desire to have aerial pictures of the Cytherean surface to analyze more closely the topography of the planet; thus, the design for the balloon probes with the imaging system is introduced. The pictures of the surface should prove to be invaluable to scientists studying fine details in the terrain of Venus.

The overall advantages of the one orbiter/bus configuration over the separate orbiter and bus are in weight and cost savings and decreased mechanical, orbital transfer, and communication complexity. The advantage to the one lander and three atmospheric probes, all with the imaging systems, is the increased data on the physical characteristics of the Cytherean surface. The mechanical arm on the lander will allow for the possibility of multiple soil sample tests. A possible disadvantage of the mechanical arm is the added complexity and risk of contamination of the inside compartment of the lander with the harsh conditions of the Cytherean environment.

Prior missions to the surface of Venus have all had relatively short life-spans due to lack of environmental control that would protect the electronic instruments from extreme heat buildup. None of the missions have deployed atmospheric probes, whereas the Ninevah mission carries three probes which will transmit previous unobtainable atmospheric data. The Ninevah mission has environmental control which consists of using the same carbon-carbon tiles used on the Space Shuttle missions to insulate the interior of the Venus lander from the extreme surface temperatures. In addition, to counteract the heat buildup of the electronic components in the lander, freon gas is utilized to cool the interior. Thus, the overall success of the Ninevah mission will be greater than any previous mission.

BACKGROUND

Since 1961, the United States and Soviet Union have been sending spacecraft to explore the planet Venus. Generally speaking, the first American spacecraft were of the fly-by variety while the Soviet's main objectives were to utilize lander probes to study Venus. What the Soviets did not anticipate was the existence of extremely high pressures ranging from 1200 to 1300 pounds per square inch at the Cytherean surface. Such high pressures were enough to crush even some of the sturdiest vehicles made for space exploration at that time. Also, no one suspected that high temperatures, averaging 870 degrees Fahrenheit, were present on the Cytherean surface. These high temperatures are a result of the greenhouse effect created by the dense cloud layer and the planet's closer proximity to the sun. As a result, if the high pressures did not crush the landers, then the extreme temperatures would significantly reduce the instrumentation lifetime. After modifications were made to later landers to withstand the high pressures and temperatures, the Russians built landers that utilized a combination of aerodynamic braking, parachuting, and free falling to land the probes on the Cytherean surface.

The American Mariner and Pioneer Venus programs were limited to a total of six missions of which only one landed successfully. This successful landing was made by one probe from the four multiprobe Pioneer Venus 2 mission. The multiprobe concept has the advantage of carrying out simultaneous studies of the Cytherean atmosphere and surface in various locations on both the day and night side. Ironically, the Pioneer Venus 2 mission was not intended to survive impact with the Cytherean surface. Through the use of aerodynamic braking and parachutes, the Pioneer's probes were to make studies of the atmosphere. However, one probe continued to operate for approximately sixty-seven minutes after impact, but did not collect any surface composition data.

The Soviet Venera program has been much more extensive than both the Pioneer and Mariner missions combined. The Soviets have sent fourteen probes, most of which landed but had lifetimes of less than seventy minutes. During these probes' short encounters of the Cytherean surface, limited but valuable data concerning atmospheric conditions and consistency, soil composition, magnetic strength of the planet, and other basic characteristics of Venus were sent back to Soviet scientists. In addition to photographs taken of the upper atmosphere, the Soviets utilized an imaging system to take a few crude pictures of the Cytherean surface. Unfortunately, these photographs were of a limited area below the lander and the pictures had to be computer enhanced to improve their clarity. However, with each successful or unsuccessful mission to Venus, more insight is gained as to how a more successful mission can be attained.

The first missions through the atmosphere and to the surface of Venus proposed an atmosphere that was similar to that of the

Earth. However, a few missions later, scientists discovered the hostile conditions which actually exist. The atmosphere consists primarily of carbon dioxide and sulfuric acid. At the surface of Venus, the temperature is approximately 460 degrees Celsius, the pressure is 92.1 bars, and the density is 65 kilograms per cubic meter. One reason for such extreme conditions, compared to Earth, is the greenhouse effect created by the thick cloud layer that covers the entire planet. This cloud layer allows heat in the form of light to pass through but traps the heat in, thereby causing the heat buildup. Also, Venus' closer proximity to the sun adds to the heating of the planet's atmosphere (108.1 x 10^6 kilometers for Venus compared to 149.5 x 10^6 kilometers for Earth). The high density atmosphere is due to the high temperatures and low gravity of the planet. The lighter gases have sufficient kinetic energy due to the high atmospheric temperature to escape the planet's gravity while the heavier gases do not. The retention of the heavier gases results in a high atmospheric density. The high temperature, high pressure, and high density will all have direct effects on the crafts sent to Venus and therefore, must be carefully analyzed. That is, a successful mission to the surface of Venus will require protection against temperatures and pressures not encountered on Earth.

TECHNICAL REPORT

Trajectory Analysis

Bus/Orbiter

The transfer trajectory of the Ninevah spacecraft is examined in essentially two programs. The first program covers Earth departure from high Earth orbit (HEO) to Earth's sphere of influence (SOI) along a hyperbolic path. Program two involves Ninevah's encounter with Venus' SOI and Venus arrival along a hyperbolic approach trajectory. Establishing orbit about Venus is made using the lowest energy maneuver possible.

The heliocentric (about the Sun) Hohmann transfer (Figure 3) utilizes the least energy for transfer. The transfer time is half the period of an elliptical orbit, and for this mission the time-of-flight is roughly 4.8 months. The Hohmann trajectory is used because this mission is a one-way, unmanned mission; therefore, flight time is irrelevant. Planetary orbits are assumed circular, and the Sun is located at the focus near Venus; thus, Ninevah is at aphelion (farthest from the Sun) at Earth departure, and is at perihelion at Cytherean encounter.

The heliocentric 'delta v's ' for Earth and Venus are the required velocity changes at both SOI of Earth and Venus to cause the Hohmann transfer. Heliocentric departure occurs at one node (where the ecliptic plane crosses Venus' orbital plane), and arrival at Venus occurs 180° later at the other node. Ninevah's transfer occurs in the ecliptic plane up until Cytherean SOI encounter.

Program One: Earth Orbit and Departure

Following the completion of Ninevah's construction in low Earth orbit (LEO), an orbital transfer vehicle (OTV) places Ninevah into a parking orbit of about 23,000 miles (37,014.9 km) in the ecliptic plane (Earth's orbital plane). The 'delta v' needed to place the Ninevah craft on a hyperbolic escape trajectory (Figure 4) from Earth is set by that required for the heliocentric departure, delta v_1, at the Earth's SOI. Applied at perigee as shown, a 'delta v' of 1.9307 km/sec places Ninevah on a hyperbolic escape trajectory. When the spacecraft leaves Earth's SOI, Ninevah has a slower heliocentric velocity than the Earth (2.499 km/sec slower), and as a result, falls in toward the Sun along the heliocentric Hohmann ellipse as shown in Figure 3.

Program Two: Cytherean Arrival and Orbit

Encounter with Venus' SOI occurs toward the end of the heliocentric transfer. By the law of cosines, Ninevah's heliocentric arrival speed, v_2, and Venus' orbital speed, $v_{[illegible]}$, determine Ninevah's velocity of 2.7107 km/sec with respect to Venus (Figure 5). This velocity, v_3, at the SOI is the hyperbolic approach speed which determines the radius and velocity conditions at pericyth**.

**Note: The term 'pericyth' is synonymous with 'perigee', and with 'perihelion', as it describes the point of closest Cytherean approach.

Arrival at the Cytherean SOI coincides with a small delta v_{PTC} of 0.16055 km/sec for a planar transfer correction. The simple plane change is small, since the ecliptic plane's angle of inclination to Venus' orbital plane is a mere 3.394°. This delta v_{P}^{TC} is applied so that it forms the base of an isosceles triangle (see Figure 5); thus, the hyperbolic approach velocity is unchanged. Any other orientation of delta v_{PTC} changes the magnitude of v_3 at the SOI, and thus, changes the trajectory of Ninevah to a less predictable pattern which might require more energy for orbital insertion (Bate, et al: p.169). The radius and velocity conditions at pericyth for the near polar orbit, as determined by the orbital elements of the hyperbolic approach, are 13,070.16 km and 7.5622 km/sec, respectively.

The circular orbit (Figure 6) is chosen over an elliptical one because surface mapping, a primary mission objective, requires constant contact with the surface. A three burn insertion was chosen because the energy requirement for the three burn insertion, delta v_c of 4.5527 km/sec, is roughly 23.65% greater than that for the two burn elliptical alternative, delta v_E of 3.4756 km/sec. The total mission energy requirement, delta v_{TOTAL} of 8.9203 km/sec, which includes a sizeable delta v for any unforeseen corrections or alterations, has been drastically reduced from previous Cytherean missions by originating the mission in HEO and using Hohmann transfers in Ninevah's transit.

The Cytherean surface is mapped at an altitude of 400 km in a circular orbit of 6587 km at an inclination of no less than

75°. Ninevah's orbital period is approximately 5,885.76 sec, or about 14.5 orbits per Earth day; thus, complete coverage of Venus' topography is assured. Venus' slow spin, which is an incredible 243 Earth days for one rotation, does not affect polar or near-polar orbits like Earth's much faster spin does. As a result, Venus experiences virtually no oblateness, or equatorial bulging, as opposed to Earth, where the equatorial bulge induces perturbative torques on near polar orbits and shifts the semi-major axis westward or eastward, depending on the direction of the orbit (Bate, et al: p.156). Solar gravity is not a factor on the near polar orbit of Venus (Cochran: meeting); all gravitational effects are assumed accounted for in the delta v calculations.

Ninevah's final circular orbit allows the surface mapping to be completed in half the rotation period of Venus, or about 121.5 Earth days (4 months).

Soft Lander and Balloon Probes

Since the actual trajectory of the soft lander is dependent on many variables such as angle of inclination upon approach and the many parameters surrounding hypersonic trajectories, the actual numbers in this section were taken from the Pioneer Venus mission. However, the values from the Pioneer Venus program should yield an excellent model for the Ninevah mission's soft lander and probes. Therefore, the sequence of events in this section is based entirely upon the successful Pioneer Venus mission.

The timing of the release of the lander and probes is critical and must be handled by computers onboard the bus. The time at which they will be released also depends upon mid-course corrections of the bus/orbiter that mission control at NASA Ames Research Center has ordered. Therefore, the release time will have to be ordered from mission control not more than a few days before actual release.

The release of the lander and probes, which are encased in the bus container (Figure 1), involves the perfect orientation of the bus with respect to the planet. This orientation places the bus' axis of rotation perpendicular to the ecliptic. Once the correct orientation is attained, half of the lander/probe container is separated from the bus using explosive bolts. Next, a spin rate of approximately five revolutions per minute is achieved so that the lander and probes can be "slung" out using centrifugal force at the precise moment to eject the small crafts. Explosive bolts also hold the lander and probes in place in the bus container. Once on their way toward the atmosphere of Venus, the lander and probes will establish communication with mission control. Also, just above 200 km in altitude, the first metered amount of freon will be released from the freon tanks inside the lander pressure vessel. This gas will help keep the internal components cool during the fiery entry into the Cytherean atmosphere. When entering the atmosphere, significant atmospheric braking begins at approximately 100 km. At around 75 km, peak deceleration of about 500 to 600 g's is reached.

Atmospheric braking will cause the lander and probes to slow down from a velocity of 41,800 kilometers per hour (kph) to a velocity of 727 kph. At these speeds and because of the dense atmosphere compared to that of earth's, excessive heating, ranging upwards to temperatures of 11,000° C, is experienced by the lander and probes. To avoid damage to the internal components, an ablative aeroshell (Figure 7) is used at the front of the lander and each of the probes and a cover is attached to the aft section thereby enclosing the whole package in a thermal protective container. The ablative coating used on the front of the aeroshell neutralizes the sulfuric acid of the Cytherean atmosphere through which the vessels pass. At approximately 65 km altitude, the main parachute of the lander is deployed and a balloon on each of the probes (Figure 8) is rapidly inflated and deployed. The deployment of both the parachute and balloons is by way of a mortar shell fired upward which pulls out the parachute and balloons. The parachute is made out of a five meter wide supersonic conical ribbon material consisting of a nylon-Kevlar-29 weave. The ten suspension lines are made of 2000 kilograms-force braided Kevlar-29. The balloon is made of a Kevlar-nylon weave that will withstand relatively high temperatures and high dynamic pressures. A mylar material will line the inside of the balloon to contain the helium which is the internal gas.

The balloon probes are be deployed in protective containers that closely resemble the encasement of the lander probe but on a smaller scale. The trajectory into the Cytherean atmosphere is also similar to that of the soft lander in both sequence of events and path followed. The only difference being that the balloon probes carry a tank of helium behind the front protective cover and which is jettisoned when the cover is removed with explosive bolts. A preset timing device for the correct sequence of events is set on the balloon probes while still onboard the orbiter/bus.

The balloons will cause the probes to reach an equilibrium altitude of approximately 30 km (prescribed altitude for the Cytherean surface observation and the altitude at which the buoyant force of the balloon equals the weight). Now, the balloons are in position and all systems are turned on by the onboard timing device. The path the balloons will take in the upper atmosphere is random since wind velocities are unpredictable.

After approximately 17 minutes and at an altitude of 50 km, the parachute on the soft lander is jettisoned. The lander will then fall slowly to the surface through the dense atmosphere much in the same way a poker chip behaves when dropped into a pool of water. The velocity at impact is no more than 40 kph. The impact of the lander will be absorbed by the legs of the lander (Figure 9). Since most damping fluids are worthless at the temperatures on the Cytherean surface, a core of crushable aluminum "honey-comb" in each leg will absorb the impact.

Propulsion

The propulsion analysis is based on a total delta v of 5.661 km/sec. The acceleration of the main orbital bus is limited to three g's to reduce the weight of the vehicle. The value of the acceleration limit is based on the space shuttle acceleration limit of three g's during launch. The following is a summary of the propulsion system parameters based upon a 26,688 Newton (N) main orbital bus and the assumption that the fuel tanks and main engine comprise two percent of the gross weight of the launch vehicle.

Thrust:	133,460 N
Engine Weight:	2668 N
Thrust Chamber Pressure:	49.88 N/m^2
Throat Area:	0.0351 m^2
Mass Flow Rate:	1399.6 kg/sec
Mixture Ratio	2
Thrust Coefficient	1.8393
Gross Propellant Weight	384,956.6 N
Propellant Tank Weight	5026 N
Main Hydrazine/UDMH Fuel Tank Volume	16.395 m^3
Main N_2O_4 Oxidizer Tank Volume	7.702 m^3
Specific Impulse	310. sec
Reserve Propellant Weight	8896 N
Reserve Propellant Tank Weight	128.99 N
Reserve Hydrazine/UDMH Fuel Tank Volume	0.4286 m^3
Reserve N_2O_4 Oxidizer Tank Volume	0.2005 m^3

The term propellant refers to the combination of the fuel and the oxidizer.

The engine chosen is a modified LEMDE. The LEMDE is the Apollo Lunar Module Descent Engine. The modification of the engine requires an increase in the chamber pressure from 24.94 N/m^2 to 49.88 N/m^2 and an increase of the area ratio from 58 to 75 while keeping the throat area constant. These modifications increase the thrust output of the throttleable engine from 43812 N to 66720 N. The engine is proven and uses a hydrazine (N^2H^4)/unsymmetric dimethylhydrazine (UDMH) fuel mixture (mixture ratio 1:1) and nitrogen tetroxide (N_2O_4) as an oxidizer. The hydrazine consists of a mixture of 82 percent nitric acid (HNO_3) and 18 percent hydrazine. The hydrazine/nitric acid mixture was chosen because pure anhydrous hydrazine has a narrow temperature range over which it is liquid and also because of the danger of decomposition induced by pressure shocks at temperatures as low as 367 K. The addition of the nitric acid decreases the freezing point from +2.0°C to -58.0°C while increasing the boiling point from 113.5°C to 119.0°C and minimizes the danger of shock decomposition by making the fuel more stable. The propellant mixture is hypergolic but an electric ignitor is used to insure the ignition of the fuel during main engine start-up. The burn characteristics of the propellant mixture are nominal but are improved with the addition of the catalyst Potassium Cuprocyanide ($K_3Cu(CN)_4$). The main improvements in the burn characteristics are a reduction in ignition start-up time and a much more stable flame in the combustor thereby minimizing the impulse loads on the spacecraft structure due to an unsteady burn.

The reaction control thrusters (RCT), shown in Figure 10, are used for orbital and perturbation corrections, and spin-up and spin-down of the main orbital bus. The RCT consist of six sets of MRE-50 monopropellant thrusters. These thrusters were used in the Mariner Mars 69, Mariner Venus, and Mercury 73 missions. The thrusters use hydrazine as a monopropellant and Potassium Cuprocyanide as a catalyst causing spontaneous decomposition. The hydrazine will be drawn off of the main propulsion system tanks, which will be maintained at a constant pressure of 24.94 N/m^2, via the main engine propellant pumps and a pressure regulator. The thrusters are arranged in two groups (one fore and one aft) of three with each group consisting of 2 radial sets and 1 axial set of thrusters. The radial sets are broken down into two subgroups based on their time of mission usage: cruise and post-large probe release (PLPR). The radial sets are arranged so that their thrust vectors are parallel and the plane that the vectors act in canted to act through the center of mass (C.M.) of the vehicle. The two radial subgroups are required because of the large change in the position of the C.M. during PLPR. Therefore, only 2 sets of thrusters, one axial and one radial, in each group will be used at any given time during the mission.

Information on hydrazine-UDMH fuel indicates that the specific impulse (Isp) varies from 250 sec to 319 sec depending on the application. Calculations based upon an Isp of 250 sec results in a mission gross weight (MGW) in excess of 45,341 kg. Calculations based on an Isp of 310 sec results in a MGW of 29,471 kg. This gross weight appears to still be excessive, but a comparison of a hydrazine-UDMH/N_2O_4 propulsion system with liquid hydrogen/liquid oxygen (LH/LOX) propulsion system reveals the hydrazine system to be the better choice. As shown in Figure 11, LH/LOX has the higher Isp and hence a projected MGW about 4,534 kg lower than the hydrazine system. The lower MGW for LH/LOX is misleading because this weight does not take into account propellant losses due to boil off during the mission.

The boil off during the 4.8 month flight is between 3,899 kg and 7,708 kg requiring an additional initial gross weight equal to the boil off weight. The comparison does not take into account the increase in MGW due to the need for cryogenic equipment to maintain the liquid hydrogen and oxygen and the increase in power requirements to run such equipment. Therefore, the hydrazine-UDMH propellant system is the better propulsion system because of its relative light weight and low power requirements.

Structures

The external tanks (Figure 12) are designed to handle a 3g acceleration which is the limit set by the space shuttle during take-off. However, this amount of acceleration will never actually be encountered during the journey to Venus. The external tanks are also pressurized to .516964 Megapascals to ensure proper propellent flow to the RCT. The tanks are constructed of AISI 304 stainless steel. This grade of stainless steel provides the maximum amount of strength without reacting with the propellants. The tanks have a diameter of 1.60 m each and are each 4.48 m long with the fuel and the oxidizer sharing a common bulkhead. Due to the limited acceleration, the skin of the external tanks is only .3175 cm thick. The tank contained in the main orbiter is called the internal tank, which contains all the propellant for attitude control. This internal tank also stores the auxiliary reserves for the main engine. This tank has a diameter of 2.80 m and a total length of only .0677 m with a skin thickness of .3175 cm also.

The main truss of the orbiter (Figure 13) channels forces from the engines to the main structure of the orbiter. Constructed of 2024-T4 Aluminum with cylindrical members of up to 2.54 cm diameter, the truss is capable of providing high strength at low weight.

Weight Estimation

The following table gives approximate weights based both on previous missions to Venus and on past and present earth-orbiting satellites.

Lander	215 kg
3- Atmospheric Probes	124 kg
Instrumentation	48 kg
Thermal Insulation	207 kg
Mission Shroud	76 kg
Solar Cells	41 kg
Ni-Cad Batteries	155 kg
Orbiter Truss	224 kg
Insulated Fuel Lines	180 kg
Fuel Tanks	156 kg
Fuel	9370 kg
Auxiliary Fuel	276 kg
Auxiliary Tank	34 kg
Engines	83 kg
Reaction Control Jet Mounts	207 kg
Lander and Probe Restraints	213 kg
Communications dish and Positioning Motor	345 kg
Total Weight	11954 kg

Communications

A crucial part of the overall mission success highly depends upon the performance of the communication system. The design of an adequate communication system would require an in depth look into the field of microwave communications and computerized data processing. These areas of study are, in themselves, very broad and beyond the scope of this paper. Therefore, since the communication systems on the Pioneer Venus Orbiter (PVO) and the Pioneer Venus Bus (PVB) proved to be reliable, the communication system of the Ninevah mission will resemble the systems used on both the PVO and the PVB with slight alterations to fit the configurations and requirements of the Ninevah mission.

Earth-based communications will begin with the utilization of the Deep Space Network (DSN) in which two 64 m dish antennas, one located in Goldstone, California and one located in Canberra, Australia, are used for direct uplink and downlink communications with the bus, lander, and atmospheric probes. All of the information received by these two antennas will be routed to Mission Operations at NASA Ames Research Center where the data will be processed and analyzed.

After launch from the earth-orbital space station, communication is established between the bus and the DSN. During the journey to Venus, all communication on the bus will be through the two (forward and aft) omni-directional antennas. The high gain and medium gain antennas will not be needed until the bus is close to Venus, which will be discussed later in this section. Next, the spacecraft is spun up to approximately 6 revolutions per minute to provide a nominal stability control rate for the craft. At this slow spin rate, the spacecraft is oriented so that the spin axis is perpendicular to the ecliptic where the rocket end is facing the sun so that the solar observation instruments are oriented correctly. Orientation is achieved by using extremely short burns on the small reaction control thrusters. Next, the magnetometer boom is deployed to measure the solar radiation flux while en route to Venus. The determination of the exact orientation and the velocity vector of the bus relative to the earth is achieved by way of comparing the difference in Doppler frequency at the stations in Canberra, Australia and Goldstone, California.

The data handling processor onboard the bus receives both analog and digital telemetry from the subsystems and science instruments. All of the information is routed to the communications subsystem for modulation on a downlink S-band carrier frequency of 2.295 Gigahertz. The command subsystem, which allows the spacecraft to carry out tasks requested by mission control, decodes all commands at the rate of 4 bits per second and either stores the information for later execution or routes commands to their correct destination. The command uplink carrier frequency is on the S-band at 2.115 Gigahertz. During the short occultation period, (time during which the spacecraft is blocked by Venus and out of the earth line-of-sight) data will be sent to the two Data Storage Units (DSU) each having a capacity of 524,288 bits. After the line-of-sight is regained with earth, the stored data is sent back to earth unmodulated using the now deployed despun high-gain antenna on an X-band frequency of 8.415 Gigahertz.

Two days before reaching Venus, orbit insertion preparation is made. Communications are still on the fore and aft omni-directional antennas. The high-gain, high-gain back-up, and the medium gain antennas are deployed. The single 1.09 m diameter dish with dual high gain antennas (one is for backup only) has an azimuth despin control and elevation positioning control for the proper earth line-of-sight orientation. In addition, the antenna has a slew control for open-loop tracking of the earth line-of-sight.

Approaching orbital insertion time, the bus, including the high and medium gain antennas are spun up to approximately 50 revolutions per minute to provide gyroscopic stiffness during motor burn. After orbital insertion, the high-gain and medium-gain antennas are despun to five revolutions per minute, the preferred rate for scientific data transmission. Next, the small reaction control thrusters are fired to orient the spacecraft spin axis perpendicular to the new Cytherean orbit.

Once in Cytherean orbit, the uplink data handling system is set up to have two redundant uplink reception channels each including one of the omni-directional antennas so that reception accuracy is ensured. Optionally, by command, the forward omni-directional antenna is replaceable by the high-gain or the high-gain back-up antenna. The high-gain antenna is used for both uplink and downlink commands but is most often used for data transmission taken from the onboard scientific instruments.

One obvious consideration during communication between earth and the Venus orbiting bus is the time for transmission to travel the some 56 million km which is approximately 3.14 minutes. Therefore, the redundant uplink reception channels are utilized to ensure correct commands since a correction would have to come at least 3.14 minutes later, which could be too late. Also, the commands will be pre-programmed, with the capability of later in-flight programming so that the data handling system will respond to known commands.

Now that the bus is correctly oriented in Cytherean orbit and the actual orbit is known, preparation is made for the release of the lander and probes. Timers are to be set on the lander and probes so that their power and systems will become operational when they hit the Cytherean atmosphere. The large probe starts warm-up first and the onboard radio receives an uplink carrier frequency from earth to provide the Doppler reference frequency for the downlink signal to earth. The small probes wait to turn on until approximately 15 minutes before entering the atmosphere to conserve battery power. They also receive an uplink carrier frequency to provide a reference downlink frequency. The orientation with respect to the earth cannot be controlled or predicted for the lander and each of the probes so, as a result, omni-directional antennas must be used which require slower transmission rates than that of the directional medium and high-gain antennas. The transmission rates will be approximately two bits per second.

When the lander and the probes make their meteoric plunge into the Cytherean atmosphere, a communication loss or blackout period will be experienced for approximately ten seconds because of the radio-impervious plasma screen that is created. During this short blackout period, data is temporarily stored in an onboard DSU for later transmission. The blackout period can be predicted by using the onboard accelerometer and triggering the command unit to order the blackout format approximately two minutes before the peak deceleration of about 500 g's. Communication resumes after the lander and probes have slowed down and begin transmitting atmospheric data.

Once the lander has reached the Cytherean surface safely, mission control maintains direct downlink and uplink communication with the lander. The lander also contains a data handling processor but on a smaller scale compared to that of the bus but it works in the same manner.

The atmospheric probes contain a relatively miniature data handling processor that is basically a downlink transmitter to send the photographs of the Cytherean surface. This transmission is achieved through the omni-directional antenna.

The complete communication network of the Ninevah mission is indeed complicated but necessary for the success of the mission. The system described in the preceding paragraphs has proved to be very reliable on both the PVO and PVB missions, but communications can not be attained without some sort of power source; therefore, the next section is dedicated to power requirements and sources.

Power Requirements and Sources

The power requirements of the Ninevah mission are estimated on the power needed by communication systems, data handling systems, instrumentation, environmental control systems, and other systems requiring electrical power. Some power requirements were based on both the PVO and PVB missions.

During the journey to Venus, the power requirements will be met through use of a 28 m^2 solar array which covers the exterior of the sensing equipment section and a 28 m^2 solar array that covers the exterior of the communication section. Since the spacecraft will be spinning, the average output of the array is approximately 1000 watts. A shunt regulator limits the amount of current delivered to the spacecraft. At the same time, power not used for instrumentation and communication is utilized to charge the Nickel-Cadmium (Ni-Cd) batteries which are to be used during the short period of darkness when Venus is between the spacecraft and sun.

Each Ni-Cd battery consists of two 12-cell packs. Each pack contains 12 individually insulated 7.5 ampere-hour Ni-Cd cells. The Ni-Cd batteries were used over the Radio-isotope Thermal Generators (RTG) because of their decreased complexity, volume, cost, and their excellent discharging and recharging characteristics. The power provided by the Ni-Cd batteries is a semi-regulated 28 volts plus or minus ten percent to all spacecraft loads. The solar array provides most of the power but when this power is not available, the Ni-Cd batteries come on line as needed. The voltage is limited on both the solar array and Ni-Cd batteries to 30 volts by seven shunt limiters.

The lander will carry two Ni-Cd batteries rated at 2.5 ampere-hours and the balloon probes will carry one 1 ampere-hour Ni-Cd battery. All of these batteries are brought to full charge starting one day before deployment.

Instrumentation

Another important aspect in the success of this mission is the reliability and survivability of the instrumentation that will be used to analyze the characteristics of Venus. In addition, the reliability of the sensors that allow mission control to monitor and alter systems aboard the orbiter/bus, lander, and balloon probes is another critical aspect of the overall mission success. In the same category of instrumentation, computers must also be used to transform the data gathered by the instruments into a code that can be transmitted back to earth for further processing. Discussion of the instrumentation, including computers, to be used on the Ninevah mission is contained in the following sections.

Orbiter/Bus

The instruments that will be included on the Ninevah mission orbiter/bus can be broken down into two categories: (1) equipment needed throughout the voyage such as navigational, computers, startracker, and communication systems, (Figure 14) and (2) equipment needed only after arrival at Venus such as temperature and gamma ray sensors, and the communication systems for the lander and probes (Figure 15). The second category must be designed for months of inactivity and then be called upon to perform flawlessly at a moments notice. The first category of equipment must be designed to work relentlessly over the 4.8 months the spacecraft will be active with a small chance of error or failure ever occurring in any part of the system.

A total of four onboard computer systems are needed for the success of the Ninevah mission, three of which are independently working in parallel and a fourth, the master computer. These four computers also act together as the main computer for the entire spacecraft. The three computers operate independently but simultaneously to ensure that all the information received is thoroughly checked by redundancy. If a conflict occurs between the three computers then the one computer with conflicting output is replaced by the fourth. If two of the computers conflict, then the fourth is brought on line to determine the correct solution. These computers will also have the responsibility of determining which instruments receive power during maximum load times so that the most information can be returned with a minimum loss of data.

The navigational computer can determine the position of the spacecraft in two ways. First, through the star tracker, a number of stars can be located and the position and velocity of the spacecraft can be determined relative to the stars. The second way is with the transponder. On earth, the signal strength can be determined from the position of the signal and from the Doppler shift of the frequency. This information then can be transmitted back to the spacecraft and that information compared with that of the startracker. The navigational computer will also have the responsibility of firing the rocket engine and the reaction control thrusters to maintain the proper course and orientation of the spacecraft.

Already discussed but highlighted again in this section, communications with the probes and lander will be the responsibility of the downlink and uplink computer. This computer determines what information can be directly transmitted to earth and what information must be stored for later transmission. This computer will also allow data to be stored until the spacecraft is in a more favorable position to transmit the collected data. This part of the spacecraft's system is responsible for transmitting the instructions to the landers and probes to ensure that the proper timing of events occurs and major experiments take place when they are supposed to.

Power needed to operate this equipment will come from the solar panels and must be transformed into a current that these instruments can use. This will be achieved through four power amplifiers, which can be brought on line individually as needed. The power amplifiers provide an input of a maximum of eighty watts and they can step that power down to fifteen watts if necessary. The power requirements of all of the instruments is not known but, it is estimated that eighty watts will be more than sufficient. These amplifiers also supply power to the Venus and sun sensing equipment and finally to the charging of the lander and probe batteries. The temperature inside the spacecraft will be regulated by sets of thermal louvers that will be placed in the walls of the spacecraft's instrument section and will be opened and closed as needed to regulate the internal temperature. Excess power will be directed to internal heaters to help keep delicate instrument containers from freezing and cracking.

The second section of instruments contains the sensing equipment needed once the spacecraft reaches orbit around Venus. One of several important instruments is the mass spectrometer It provides a look at the ionosphere of Venus and how the ionosphere intersects with the solar wind. It is capable of providing the sensitivity, resolution, and dynamic range needed to obtain data on the bow shock produced by the solar wind and the Cytherean atmosphere.

Based on the electric field detectors of Pioneer 8 and 9, the plasma wave detectors are capable of providing measurements of the plasma layer of gases that lay just outside the planet's atmosphere. The plasma wave detectors were used with great success at Jupiter and Saturn and should provide useful information about the atmosphere of Venus. This instrument can determine the atmospheric ionization and it is sensitive enough to record upper atmospheric lightning and determine its position, duration, and intensity.

The ultraviolet spectrometer is used to determine the amount of back-scattered light from the planet. This instrument can determine how much of the solar radiation falls on the planet and is absorbed by the atmosphere and how much is reflected back into space. This instrument consists of a 250 mm Cossegrainian telescope which can be set to accept a wide range of light from thirteen Angstroms to thirteen hundred Angstroms.

The neutral gas spectrometer is used to determine the horizontal and vertical densities of the atmosphere between 150 km and 300 km. This unit is a cylindrical instrument with a diameter of 15 cm and length of 22 cm and requires twelve watts of power.

Earth orbiting satellites provide a clear view of the interaction of the solar wind with the strong magnetic field. Venus on the other hand does not spin as fast as the earth and therefore does not have a strong magnetic field. The fluxgate magnetometer should show what type of distortion takes place between Venus' magnetic field and the solar wind.

The only instrument that will be used to observe the sun will be the gamma-ray burst detector. This instrument is the only one that would be at an optimum distance from the sun to provide any substantial data return.

The radar mapper is designed to obtain a global picture of the topology of the surface of Venus with a meter scale resolution. Also, the mapper can take images at oblique angles to determine depth and height of geological features. The footprint of the radar (i.e. how big a picture the radar can take) is determined by the orbital altitude and the resolution required. The footprint sizes can vary from 10 km wide at an altitude of 100 km to 50 km wide at 470 km. Because of the sensitivity of the radar, it must be within 550 km of the surface. The radar antenna is positioned with a single step motor. The radar requires nine watts power in stand-by mode and fifteen watts when in operation.

<u>Lander</u>

One of the main reasons for going to Venus is to place a soft lander (Figure 9) on the surface of the planet that will survive long enough to take atmospheric samples, soil specimens, and pictures, a task the United States has yet to achieve. This lander would insure accurate surface data that, before now, was only unconfirmed or speculated data. The lander must be designed to withstand not only the inhospitable conditions of the planet's surface, but also the freezing cold of space during its journey to Venus.

During the lander's voyage to Venus, the lander and probes will be enclosed in their respective aeroshells and all power and communications will be supplied by the orbiter until the moment when the lander and probes will be separated from the orbiter. This will be done by a set of explosive bolts that will hold the lander and probes in the mission container. Once these bolts have been severed, centrifugal force due to spin will send the lander/aeroshell and probes/aeroshell out of the mission container and on their way to encounter Venus. There is no course correction equipment onboard the lander/aeroshell or probe/aeroshell so all positioning adjustments must be made by the orbiter before separation. The approximate atmospheric trajectory has been discussed in more detail in the trajectory section (lander) of this report. However, to relate events to instrumentation, the trajectory is highlighted again.

Once on its way, the lander will not begin communicating with earth until it has begun its decent into the Cytherean atmosphere. The lander, still sealed in its aeroshell will deploy the upper atmospheric meteorological equipment and begin relaying data back to earth. Once the lander/aeroshell, still in freefall, passes through the cloud of weak sulfuric acid at an altitude of approximately 50 km, a 15 inch mortar will fire upward releasing the drogue parachute. The upper atmospheric meteorological sensors, now contaminated with sulfuric acid from their encounter with the cloud layer, are jettisoned along with the aft cover of the aeroshell (Figure 7). This, in turn, deploys the main parachute which further slows the descent of the lander.

As soon as the parachute is fully deployed, the bottom of the aeroshell is dropped which deploys the lower atmospheric meteorological equipment along with the lander legs. At an altitude of 50 km, with the parachute fully deployed, the imaging system is activated so that long range pictures of the surface can be taken as the lander descends toward the surface.

Once the lander has reached the Cytherean surface safely, no time can be wasted since the lifetime of the lander is fairly limited. This entails the first soil sample being made without the input of human intelligence. Therefore, some form of artificial intelligence will have to determine from where the first sample is to be taken. By the time pictures of the landing sight and the information of the first sample reach earth, scientists will be able to determine the second and possible third sample sight.

To maintain the highest structural integrity possible, the number of ports and windows are kept to a minimum. Therefore a single cylindrical rotating airlock will be used to bring in soil and atmospheric samples (Figure 16). The airlock is composed of a series of isolated expansion chambers which will allow the gases trapped in the airlock to expand and cool as the airlock cylinder is slowly rotated. The expansion chambers will be pumped out to the collection tanks on board after retrieval of each sample. The expansion and cooling of the samples will minimize damage to the sampling chamber of the lander due to significant pressures differences and extreme temperatures. The atmospheric and soil samples will not be taken in at the same time, because the analyzer would not know what gases are in the atmosphere and what gases came from the soil.

The imagery system is set up to photograph pictures through a sapphire window on the top of the lander where a periscope type arrangement can vary the altitude and position of the lens. With this system the fixed camera can capture a 180° panoramic view with almost 90° elevation.

Anatomy of the Lander

Not only must the lander (Figure 9) be able to survive the intense pressures, corrosive chemicals, and temperatures that are present throughout the atmosphere but the lander must also withstand the 400 to 500 g deceleration that entry into the atmosphere creates. To protect the instruments, a 2.5 m diameter stainless steel sphere is used with a wall thickness of .034 m. This sphere is insulated with the same carbon-carbon tiles used on the space shuttle which will provide the thermal protection required for the delicate internal instruments. Internally mounting these tiles prevents the corrosive gases of the atmosphere from eroding the tiles and the glue that holds them in place. Four tanks of freon are located in the bottom compartment of the lander, which releases the gas at a slow rate to help keep internal temperatures down (freon will be safe for the electronic components as it is used today in troubleshooting electronics). The freon gas cools the internal equipment thereby extending the lifetime of the lander. After the internal temperature reaches a prescribed limit, the now heated freon gas is pumped into a small insulated, evacuated tank. Then, more cool pressurized freon gas is released inside the lander. This cycle is repeated as long as the freon supply lasts. Along with the freon tanks in the bottom compartment are the two nickel-cadmium batteries that provide 30 watts of electrical power for the entire lander.

The upper deck of equipment is arranged around the imaging camera. This camera points straight up through the sapphire window that uses a maneuverable periscope mirror to position the lens. The computer and communication systems are located next to the imaging camera and the soil and atmospheric sampler are opposite the computer on the other side of the camera. Also on the upper deck is the rotating airlock. This airlock rotates between the soil sampler sensors and the exterior of the lander.

Exterior to the lander is the meteorological boom which contains the barometer, wind sensors, and temperature gauges. The information received from these instruments is sent to the data handling system (computer) where it is compiled and then transmitted to earth on the correct carrier frequency. Also outside the lander is the omni-directional antenna which is used to send the information to earth. The only other equipment outside the lander other than the periscope mirror system is the sampler mechanical arm. Built similar to the extendable roller arm on the Viking mission, the sampler arm will employ a wrist and roller arm driven by tiny electric motors that will allow a sample of soil to be dug and deposited in the rotating airlock.

Balloon Probes

The balloon probes (Figure 8) will be most valuable to scientists in that the images created will allow scientists to study the fine topographical features of the Cytherean surface.

Although not on the surface of Venus, the balloon probes will still have to withstand temperatures of approximately 220°C and pressures of 945,000 N/m² while floating at an altitude of approximately 30km. At this altitude, scientists have speculated that visibility will be very good down to the surface since this altitude is below the lower cloud layer. Above approximately 35 km, cloud layers are too dense for clear images of the surface. Below 30 km, pressures and temperatures become too high for operation of the imaging system.

The imaging system to be carried by the balloons is the same as that carried on the lander. The system is enclosed in a spherical stainless steel pressure vessel of wall thickness .020 m and diameter .75 m. The system is attached to the balloon using a short two meter Kevlar tether. Atop the probe sphere, an omni-directional antenna is used to transmit the images to earth. Inside the probe is the imaging system which includes a small one ampere-hour Ni-Cd battery, the high-resolution camera system, and the small but efficient data handling system that transmits the image at two bits per second.

The approximate weight of the floating imaging system is

91 kg which requires a balloon diameter of 2.7 m to provide the buoyant force for the imaging system. The gas to be pumped into the deflated balloon upon entering the atmosphere is helium. The imaging system will be the same as that aboard the lander, except for no "periscope" setup. The camera lens on this imaging system will also peer through a sapphire window. All pictures taken of the planet's surface will be sent directly back to earth to be developed and carefully analyzed.

Cost Estimation

The following approximated cost list is compiled from past missions and present technology.

Lander/Probes	130 million
Structure	10 million
Imaging System	230 million
Communications	100 million
Soil Sample Equipment	90 million
Computer System	170 million
Propulsion and Fuel	150 million
Main Orbiter	340 million
Instrumentation	260 million
Launch	40 million
Support	30 million

Total Mission Cost	1.55 billion

BIBLIOGRAPHY

Barker, P.C., et al, "Pioneer Venus Multiprobe Spacecraft Mission Operational Characteristics Document", NASA CR-166261, PC-403 Volumes 1,2, and 3. Hughes Aircraft Company, May 1978.

Bates, R. R., Mueller, D. D., and White, J. E., Fundamentals of Astrodynamics, Dover Publications, New York, 1971.

Colin, Lawrence and Fimmel, Richard, "Pioneer Venus", NASA Publication SP-461, Washington D.C., 1983.

Fimmel, Richard O. and Colin, Lawrence and Burgess, Eric, "Pioneer Venus", NASA SP-461, NASA Scientific and Technological Information Branch, Washington D.C., 1983.

Findley, J.T. and Kelly, G.M., "A Recommended Entry Reconstruction Process for the Pioneer Venus Multiprobe Mission", AMA Report No. 78-18, Contract No. NASA-15055, Analytical Mechanics Associates Inc., Hampton Virginia, November 1978.

Gathand, Kenneth, The Illustrated Encyclopedia of Space Technology, Salamandef Books Ltd., New York, 1981, pp. 106-116.

Geoscience and Remote Sensing, January 1980, Volume 18, number 1, pp. 5-76.

Johnson, Nicholas L., Handbook of Soviet Lunar and Planetary Exploration, Univelt, Inc., California, 1979.

Hill and Peterson, Mechanics and Thermodynamics of Propulsion, Addison-Wesley Publishing Company, Massachusetts, 1970.

Langdon, N.H., "Rocket Propulsion, Vol.2", American Elsevier Publishing Company, New York, 1970.

Lewis, Richard S., The Illustrated Encyclopedia of the Universe, Salamander Books Ltd. 1983, pp. 152-170.

Malone, Hugh, Analysis of Rocket Propellants, Academic Press ,London, 1976.

Miller, R.B. and Ryan, R.E., et al, "Telecommunications and Data Acquisition Support for the Pioneer Venus Project", NASA CR-173893, Jet Propulsion Laboratory, Pasadena, California, March 1984.

Paushkin, (Translated by Jones, W.), The Chemical Composition and Properties of Fuels for Jet Propulsion, Pergamon Press, New York, 1962.

Siegel and Schieler, Energetics of Propellent Chemistry, Wiley and Sons, New York, 1964.

Sutton, George, Rocket Propulsion Elements, Second Edition, Wiley and Sons, New York, 1956.

Sutton, George, Rocket Propulsion Elements, Fifth Edition, Wiley and Sons, New York, 1986.

Washburn, Mark, Mars at Last, Putnum and Sons, New York, 1977.

Wilkins, R.L., Theoretical Evaluation of Chemical Propellants, Prentice-Hall Inc., New Jersey, 1963.

ORIGINAL PAGE IS
OF POOR QUALITY

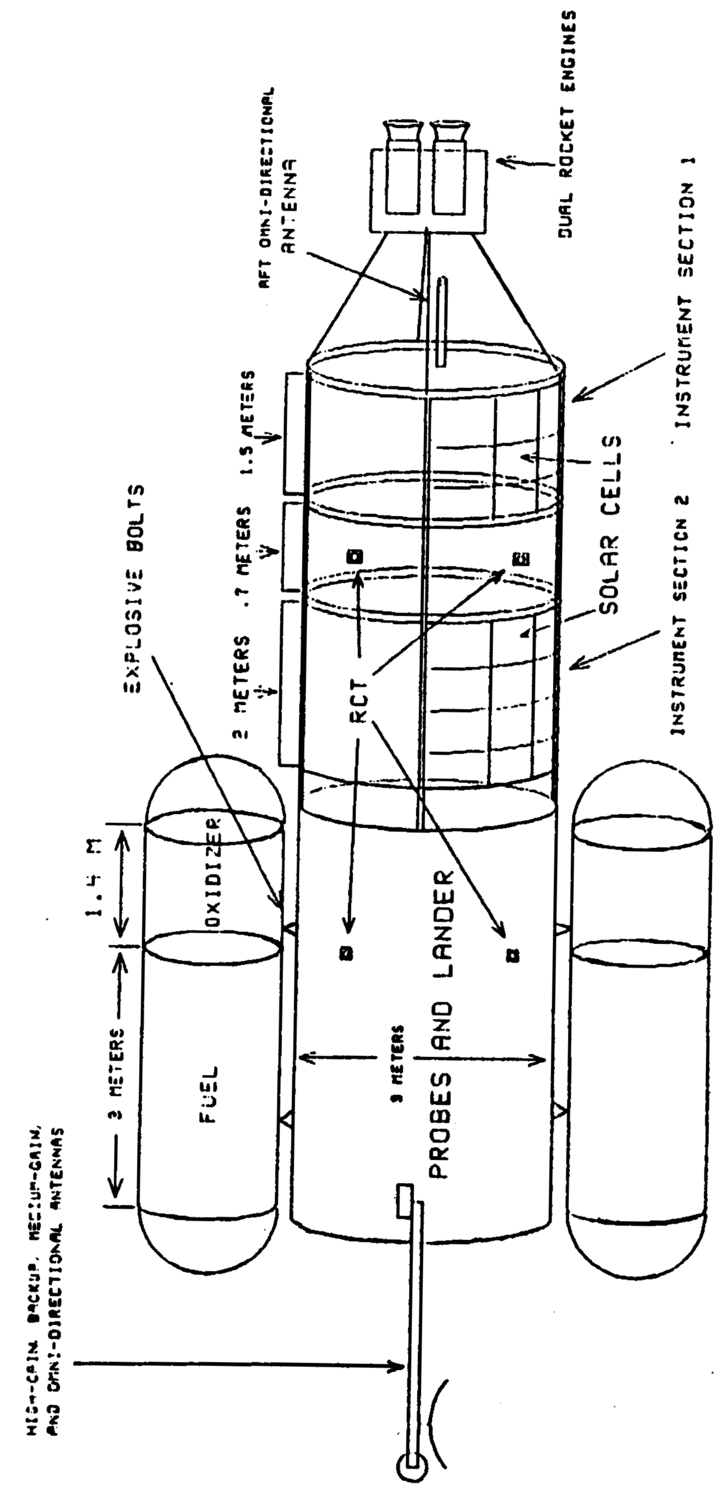


FIGURE 1. NINEVAH SPACECRAFT
CONFIGURATION

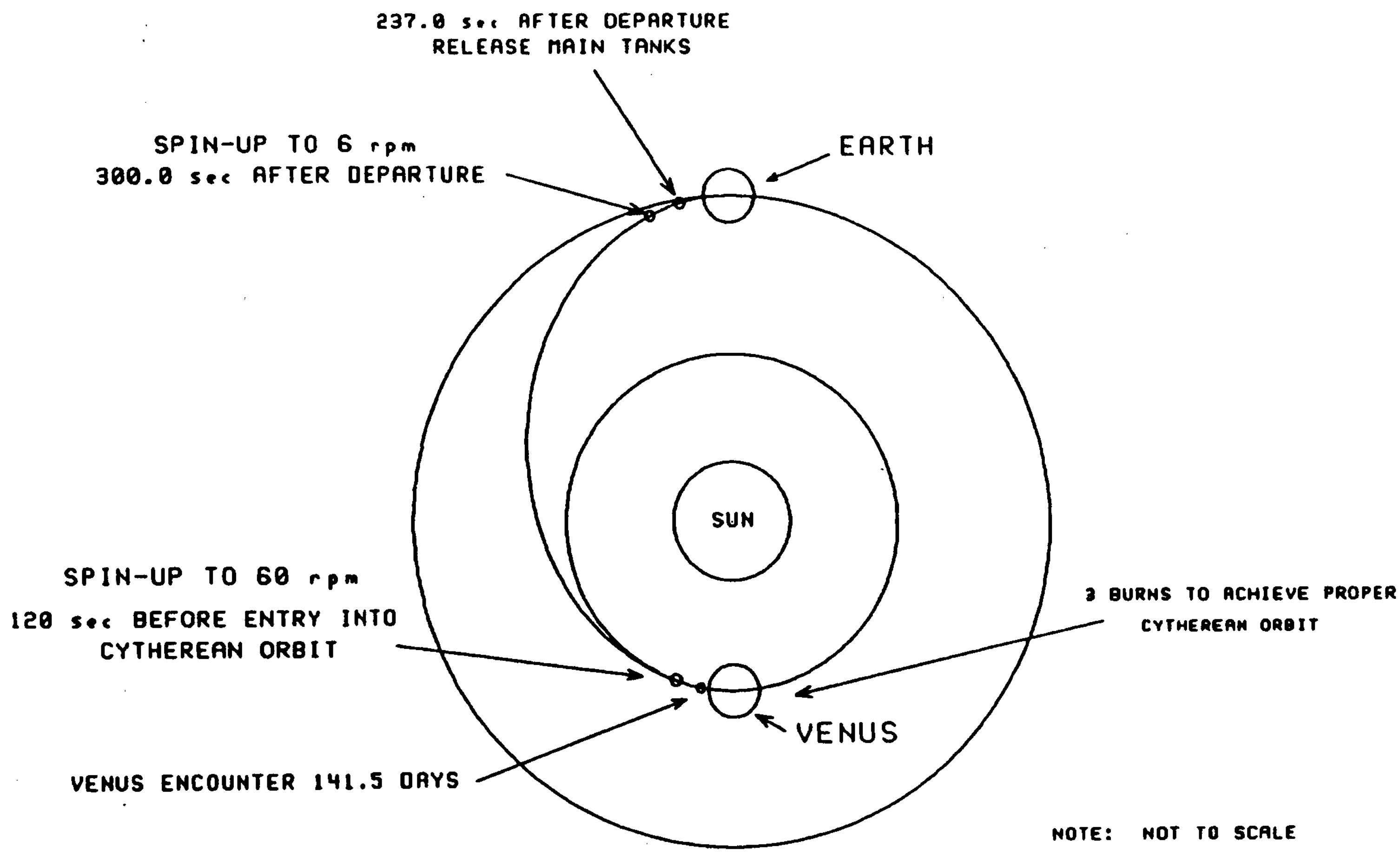


FIGURE 2a: HELIOCENTRIC MISSION PROFILE

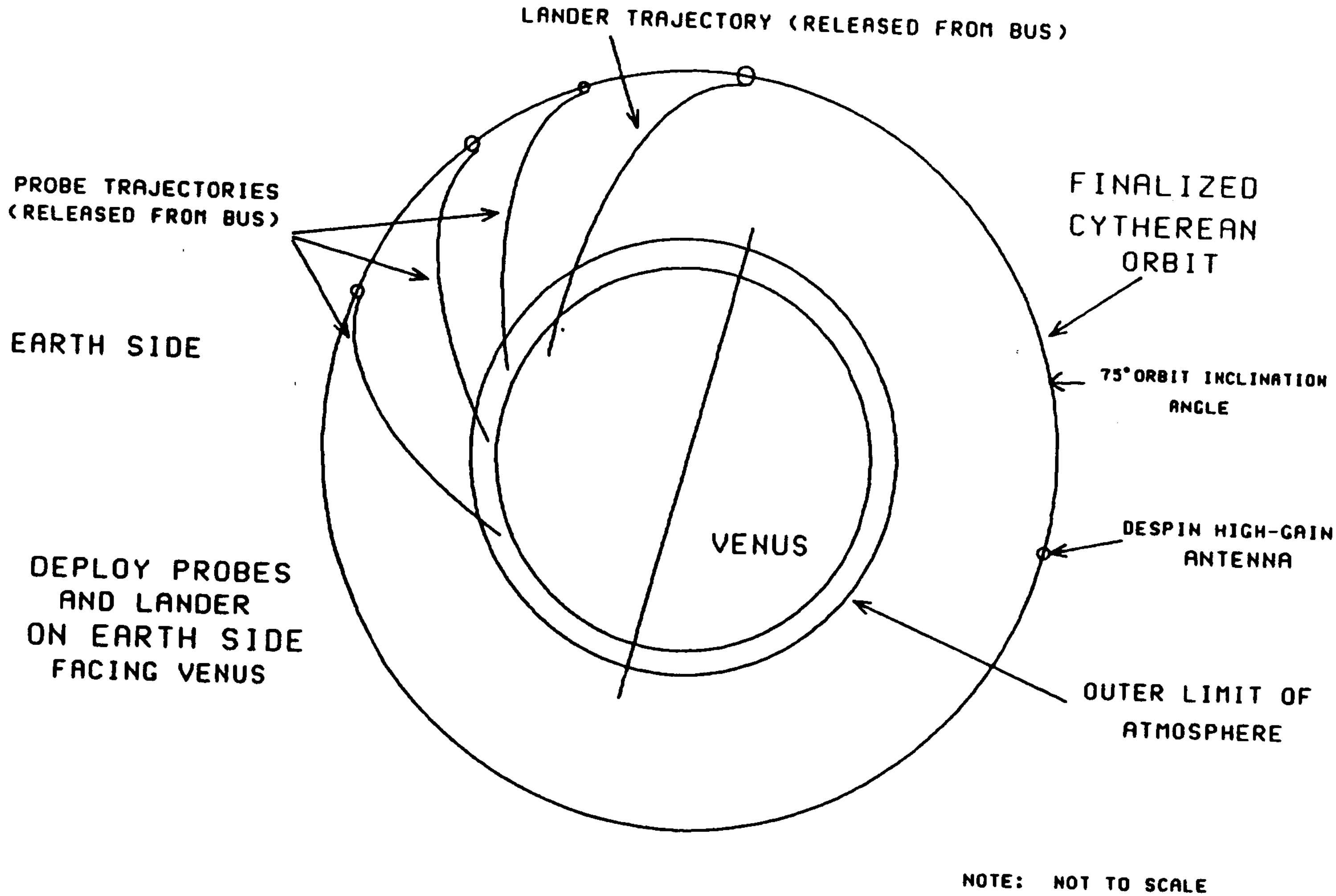
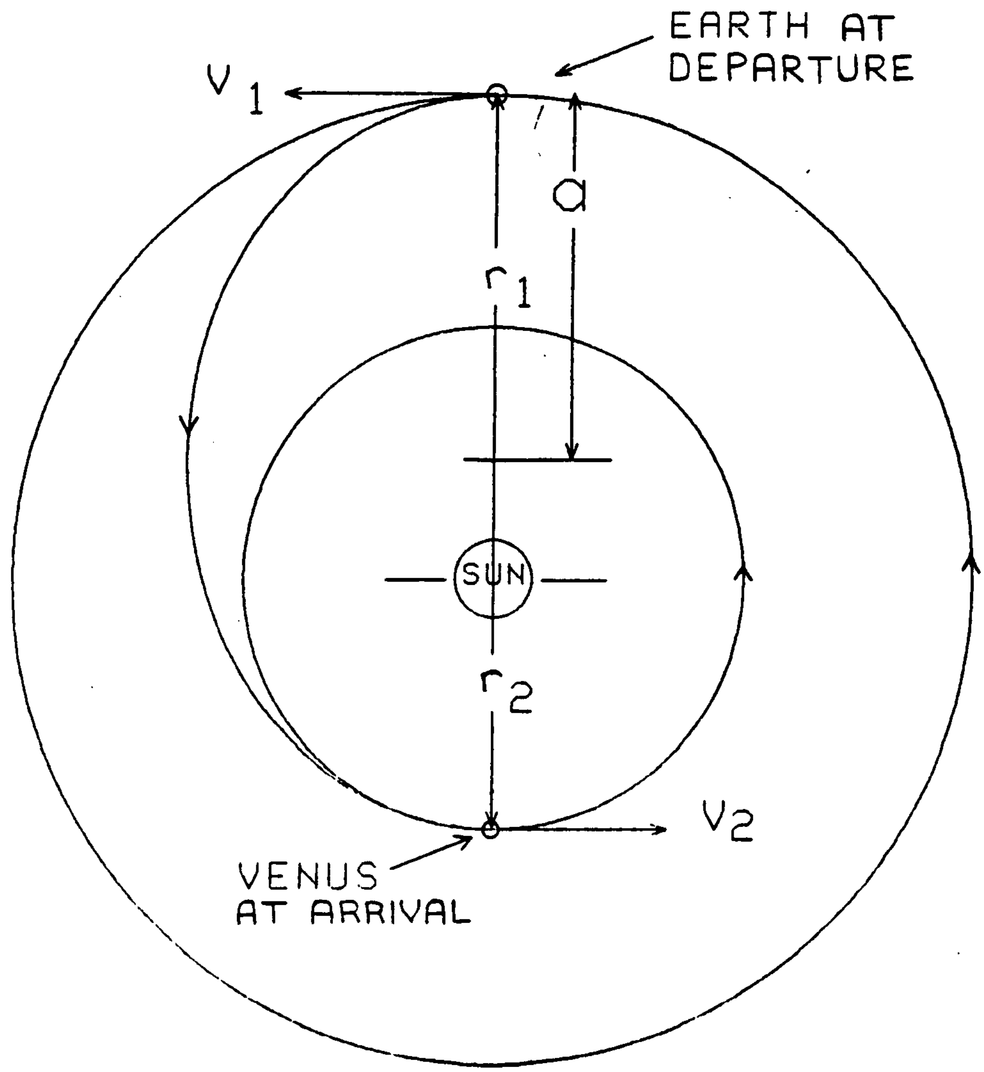


FIGURE 2b: CYTHEREAN MISSION PROFILE



TIME OF FLIGHT = 4.8 MONTHS

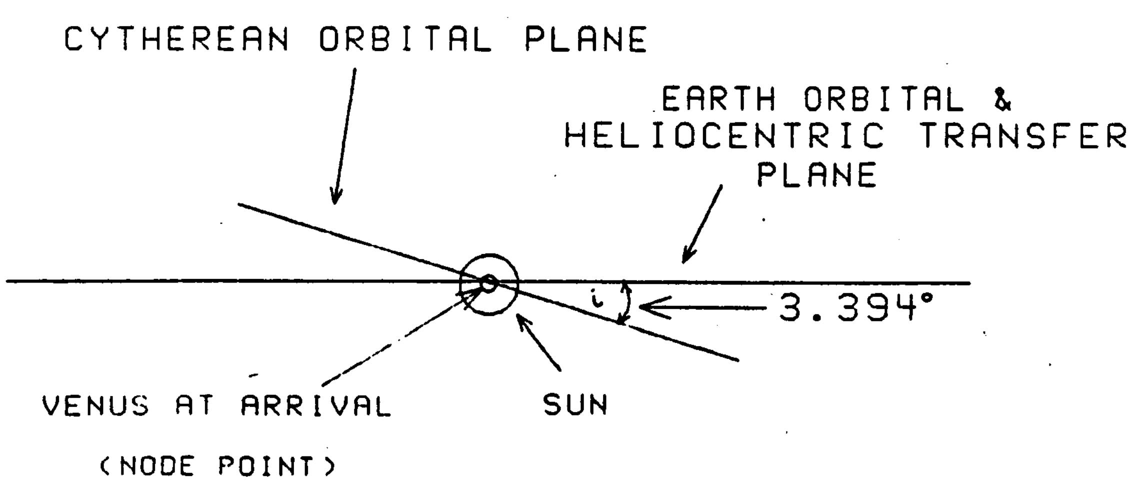


FIGURE 3: HELIOCENTRIC HOHMANN TRANSFER

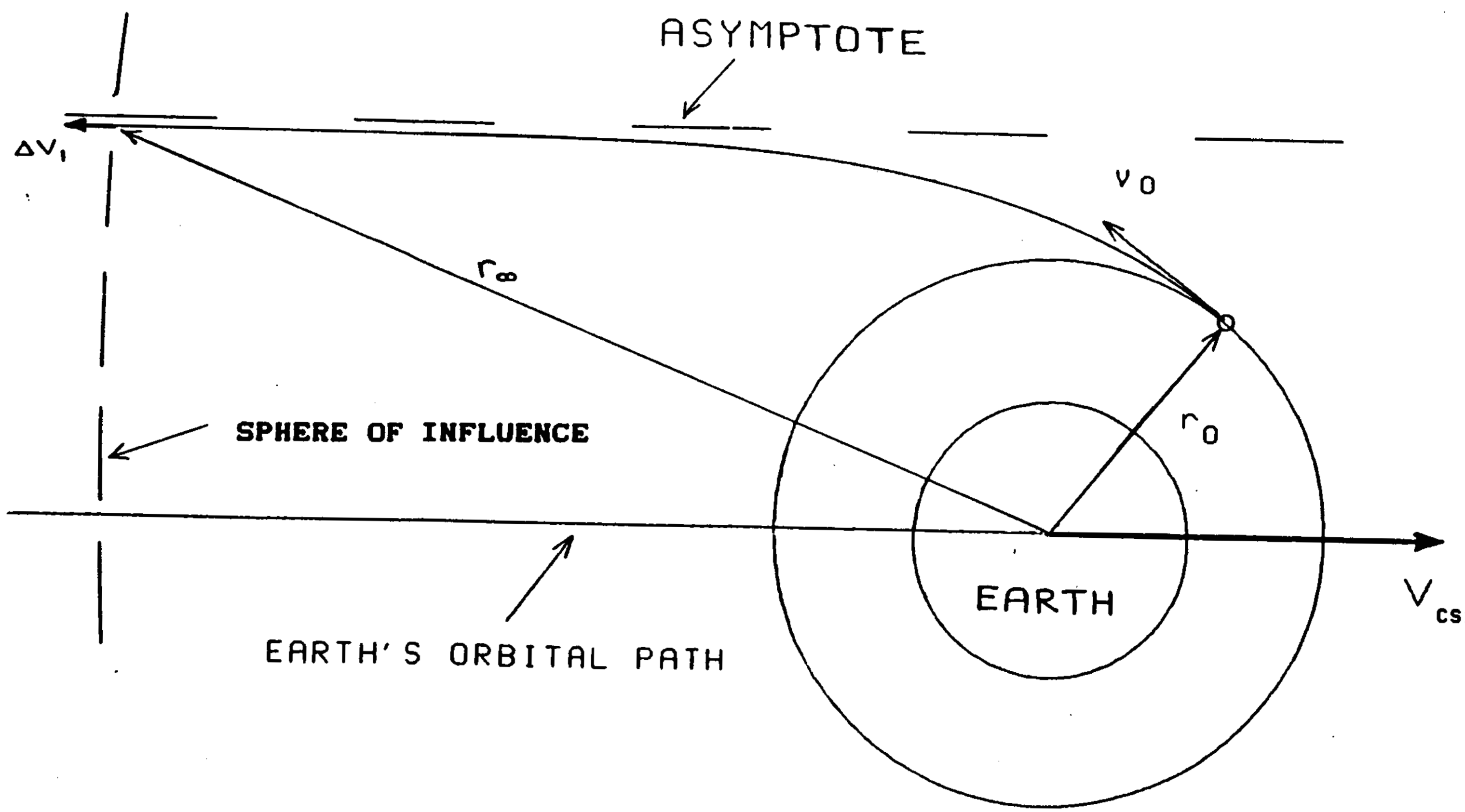


FIGURE 4: HYPERBOLIC ESCAPE FROM EARTH

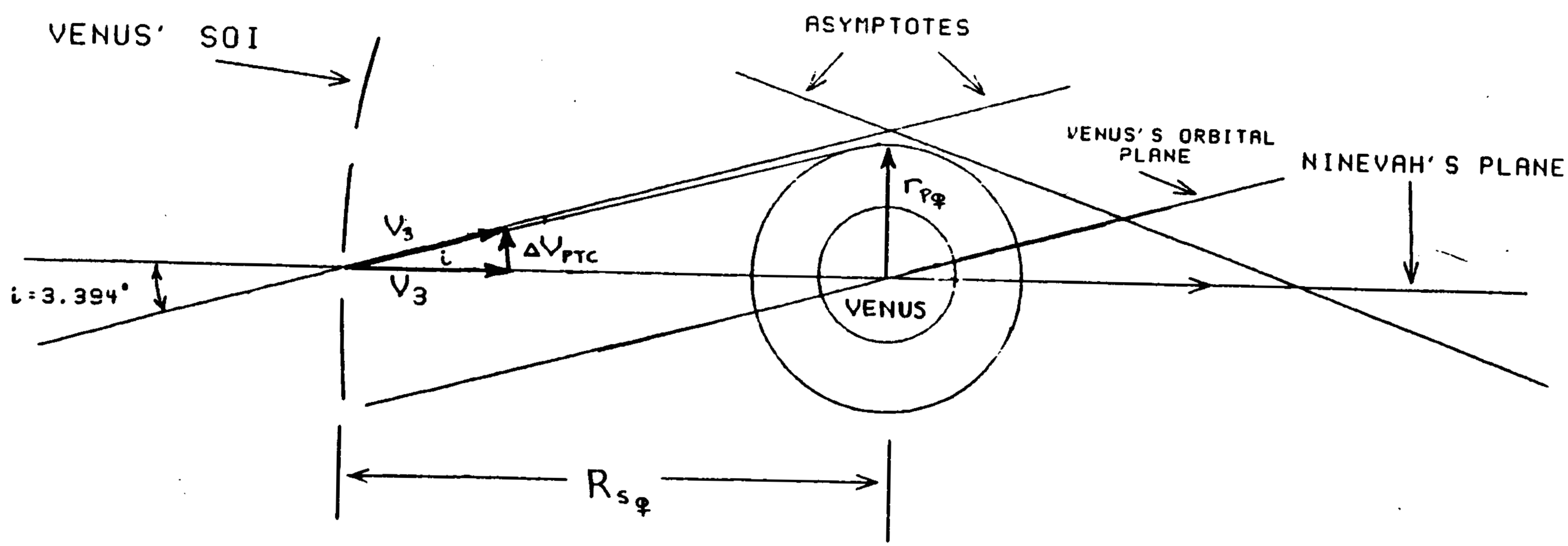
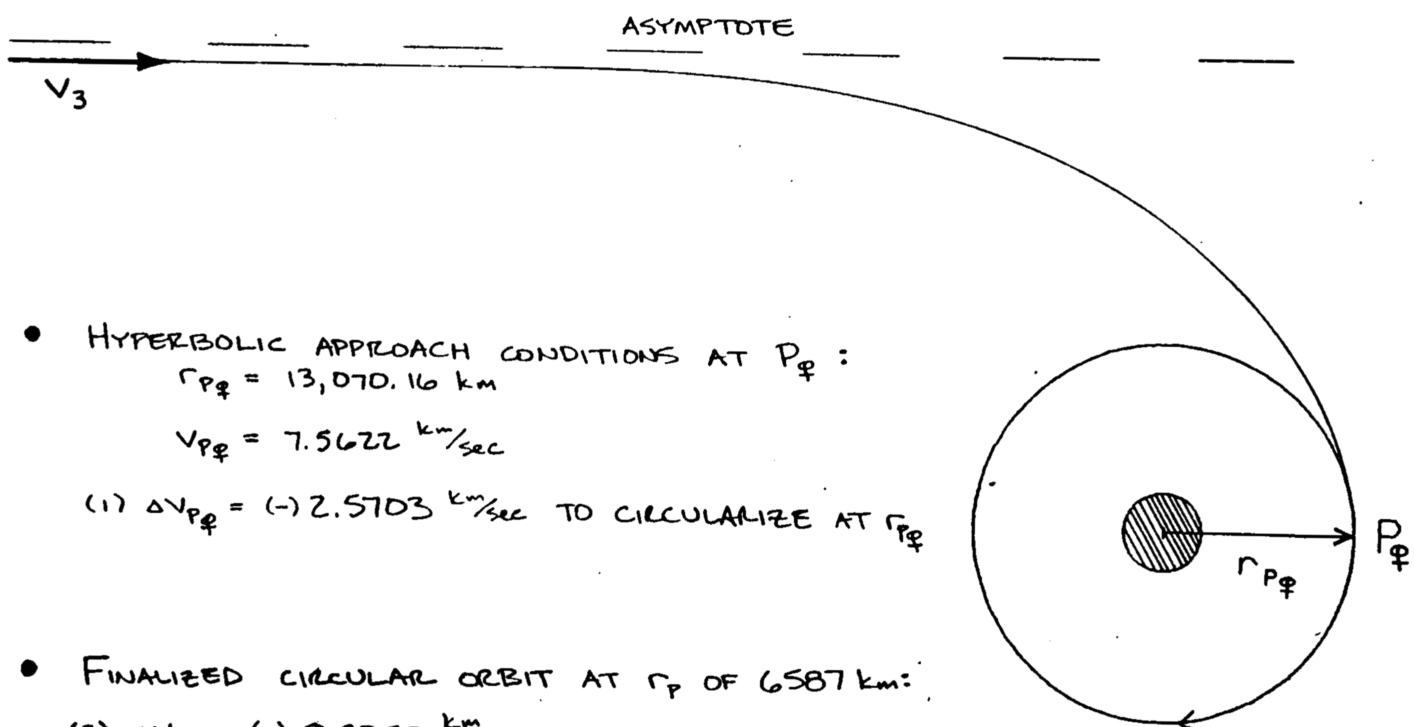


FIGURE 5: HYPERBOLIC APPROACH TO VENUS

ORIGINAL PAGE IS
OF POOR QUALITY



- HYPERBOLIC APPROACH CONDITIONS AT $P_{♀}$:

  $r_{P♀} = 13{,}070.16$ km

  $V_{P♀} = 7.5622$ km/sec

  (1) $\Delta V_{P♀} = (-)\,2.5703$ km/sec TO CIRCULARIZE AT $r_{P♀}$

- FINALIZED CIRCULAR ORBIT AT r_P OF 6587 km:

  (2) $\Delta V_A = (-)\,0.9053\ \frac{km}{sec}$

  (3) $\Delta V_P = (-)\,1.0771\ \frac{km}{sec}$

  $\Rightarrow \Delta V_{C_3} = \Delta V_{P♀} + \Delta V_A + \Delta V_P$

  $\underline{\underline{\Delta V_{C_3} = (-)\,4.7752\ \frac{km}{sec}}}$

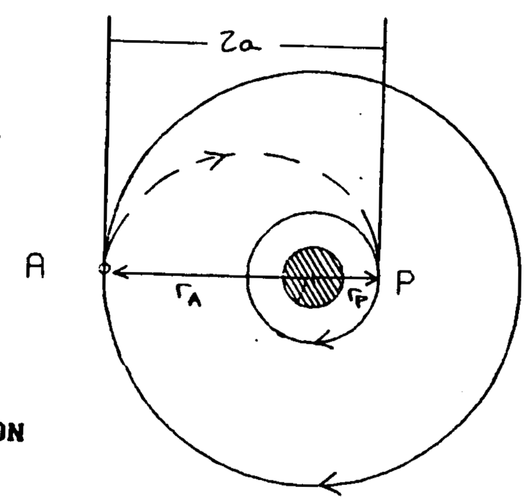


FIGURE 6: THREE-BURN

CIRCULAR ORBIT INSERTION

ORIGINAL PAGE IS OF POOR QUALITY

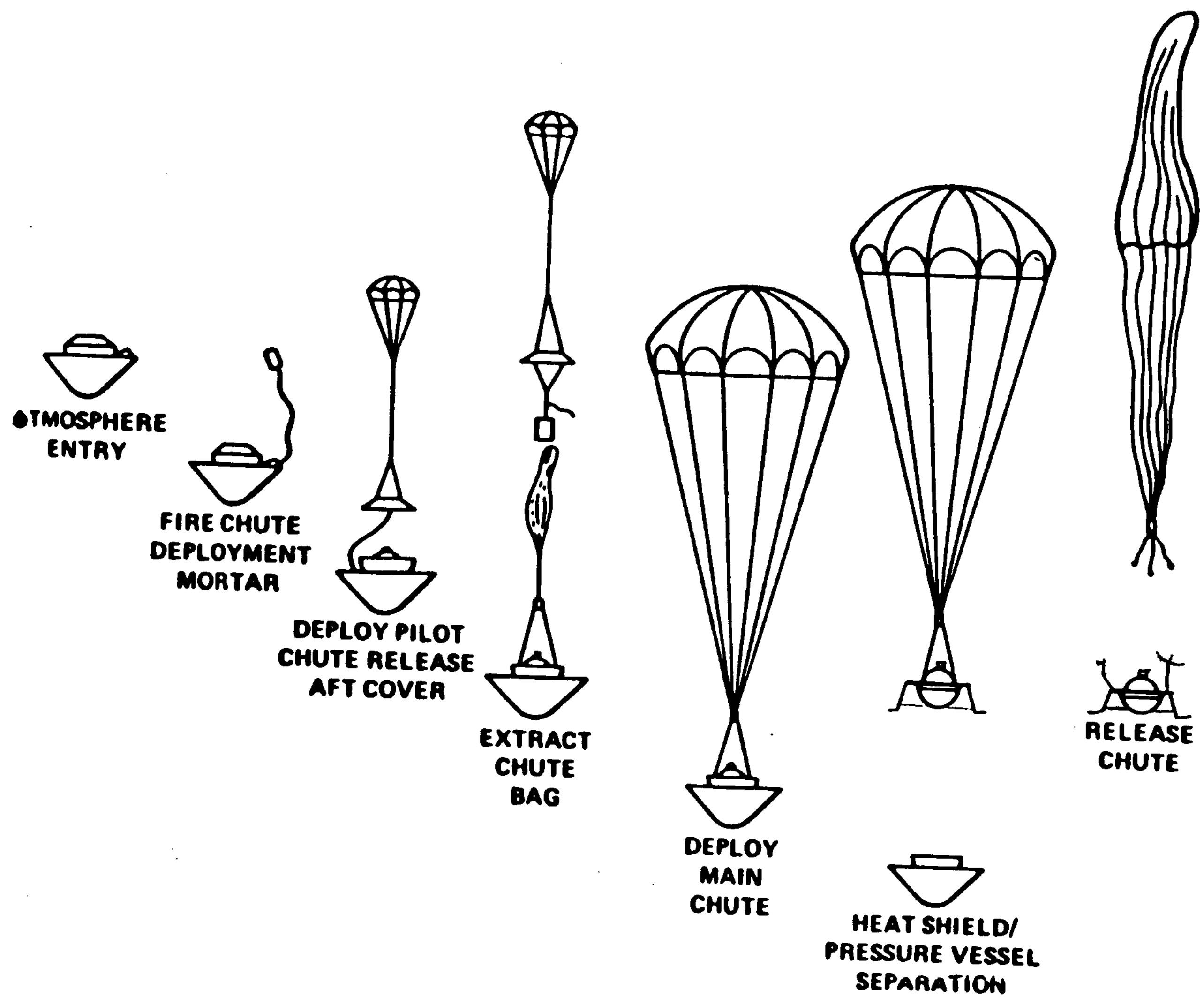


FIGURE 7: LANDER DEPLOYMENT SEQUENCE

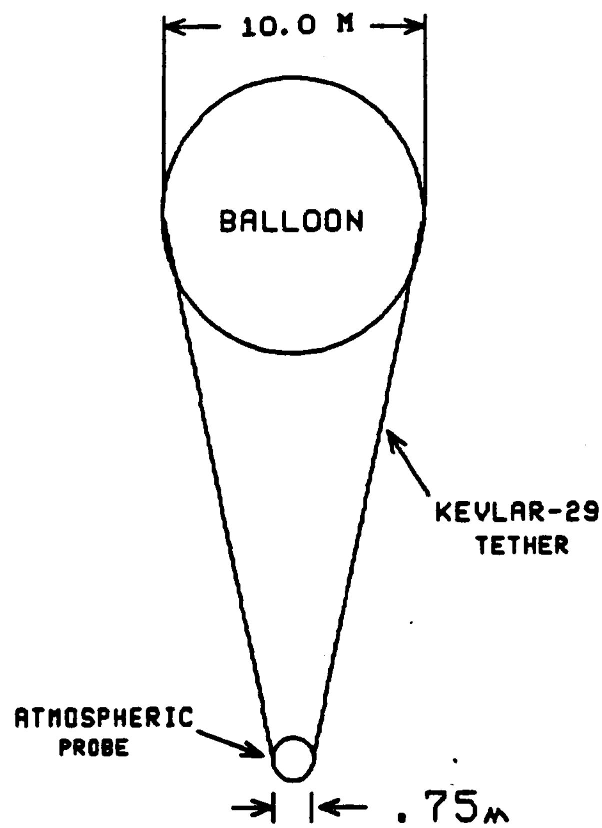


FIGURE 8: BALLOON PROBE

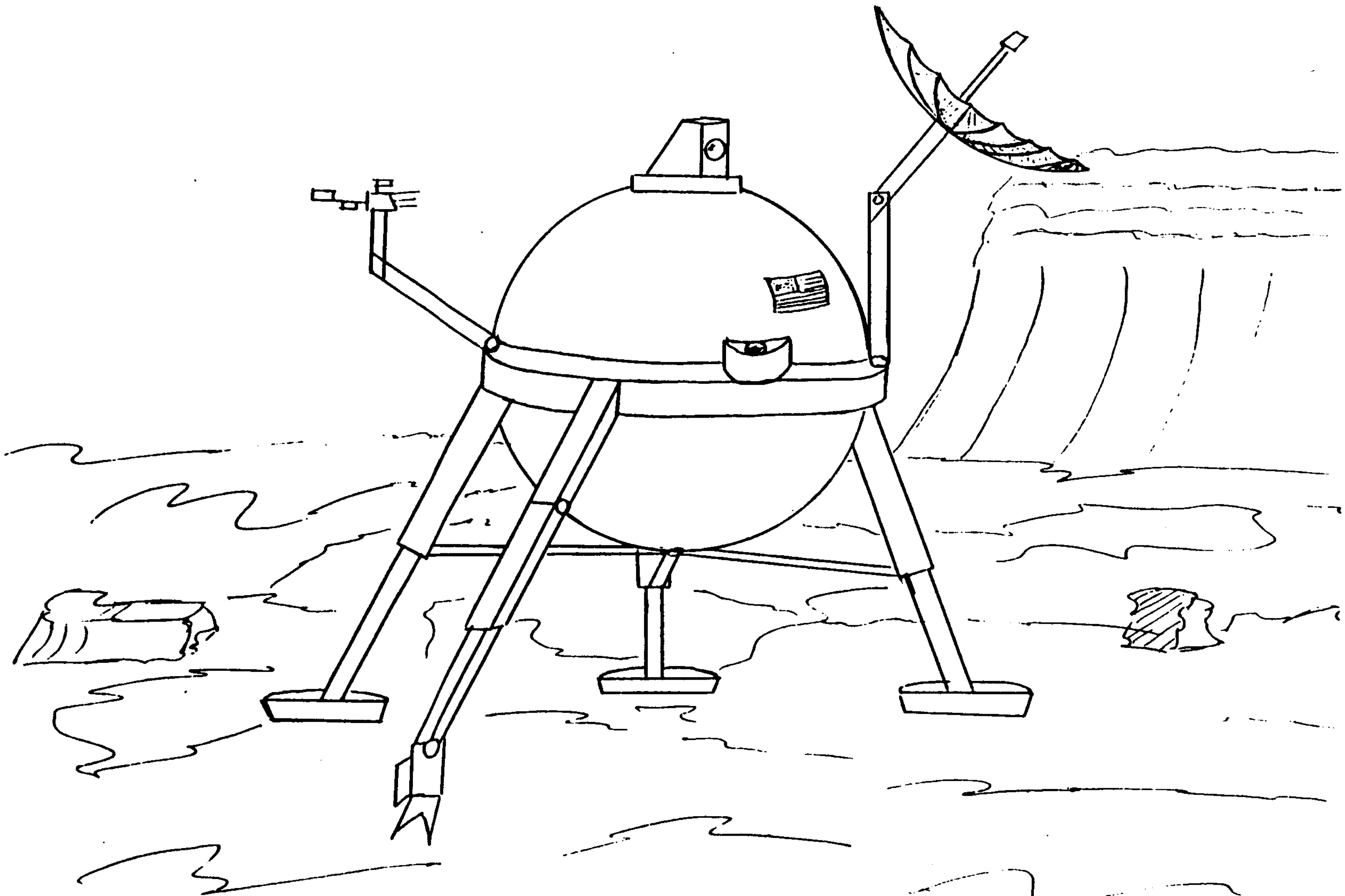


FIGURE 9: VENUS LANDER

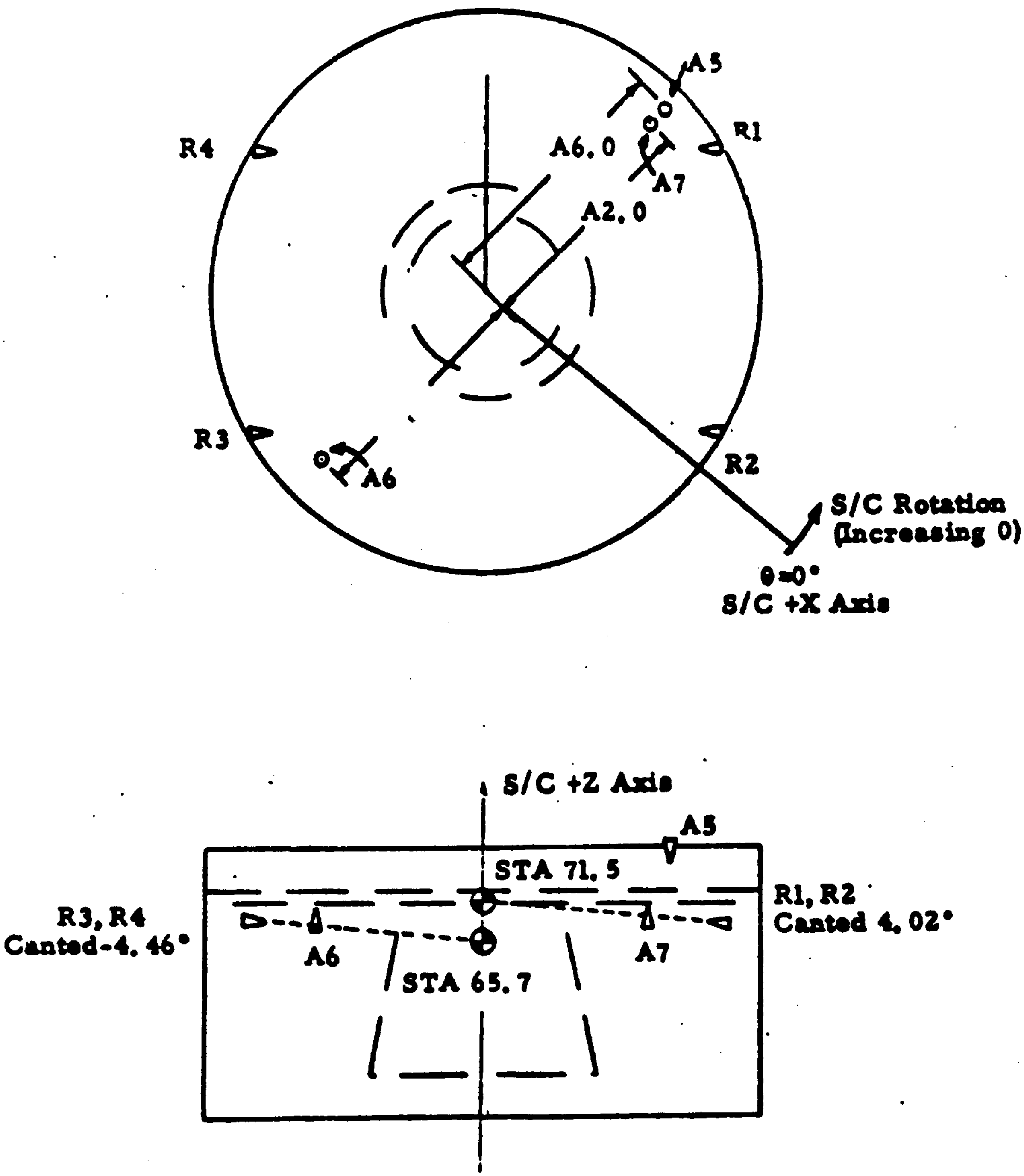


FIGURE 10: REACTION CONTROL THRUSTER CONFIGURATION

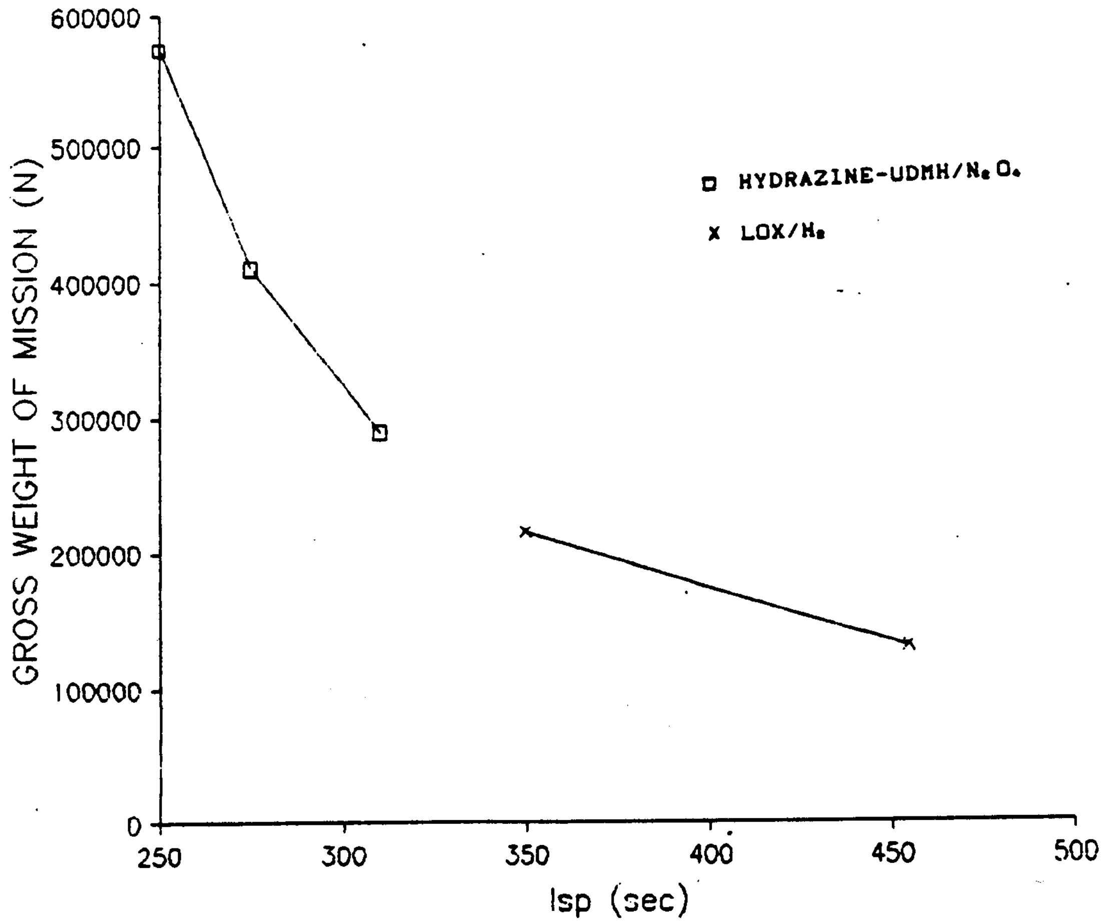


FIGURE 11: MISSION GROSS WEIGHT VERSUS SPECIFIC IMPULSE

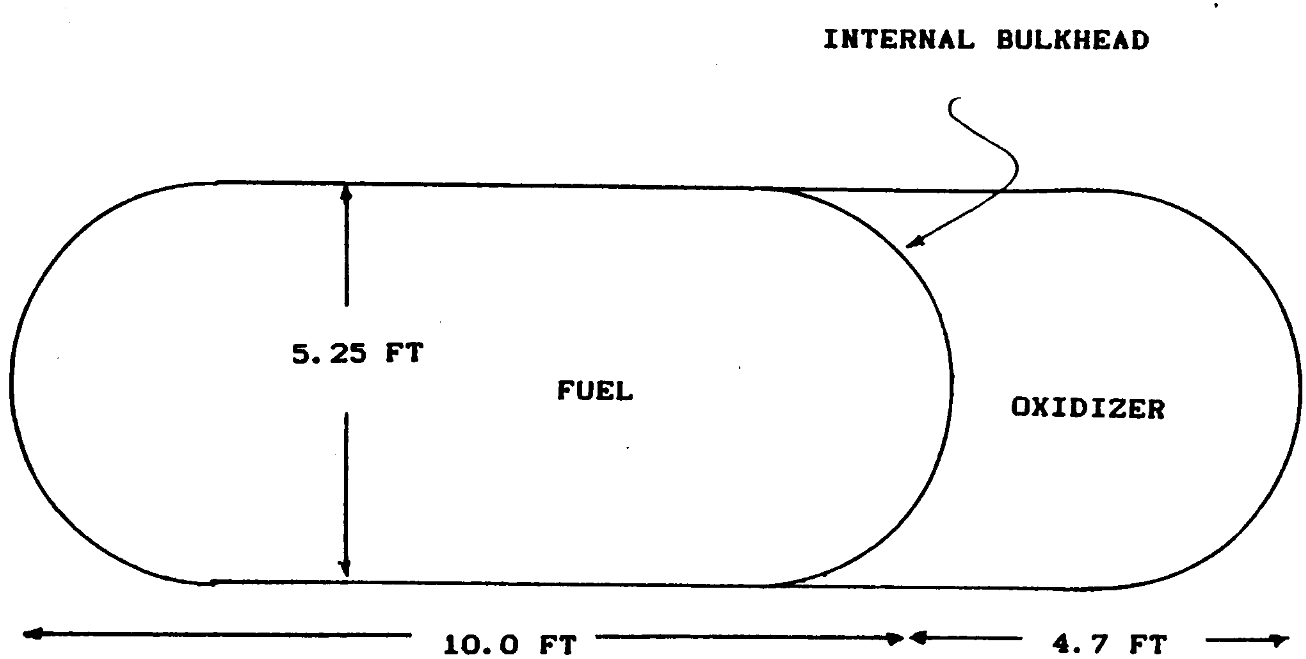


FIGURE 12: SCHEMATIC OF EXTERNAL FUEL TANK

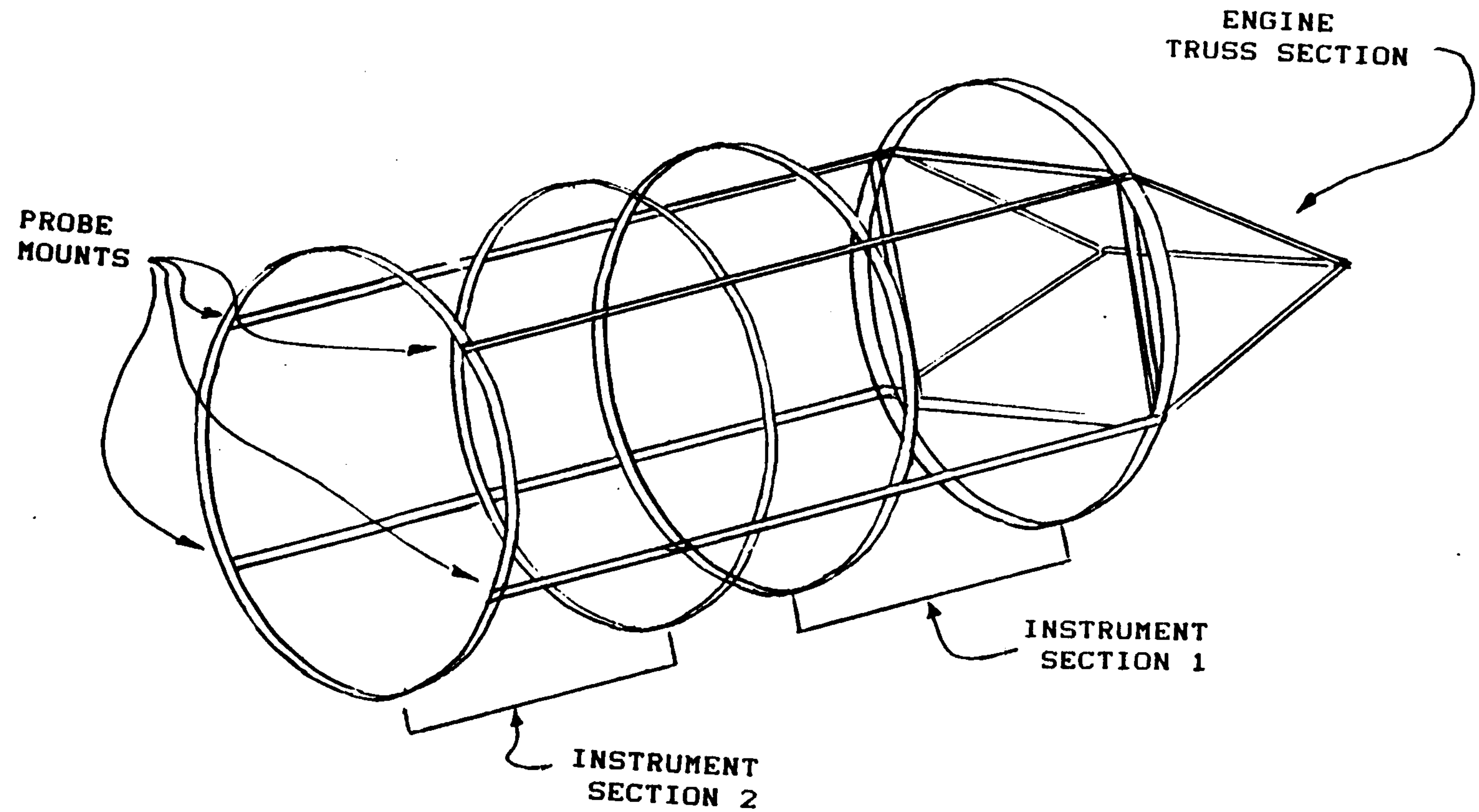


FIGURE 13: ORBITER TRUSS CONFIGURATION

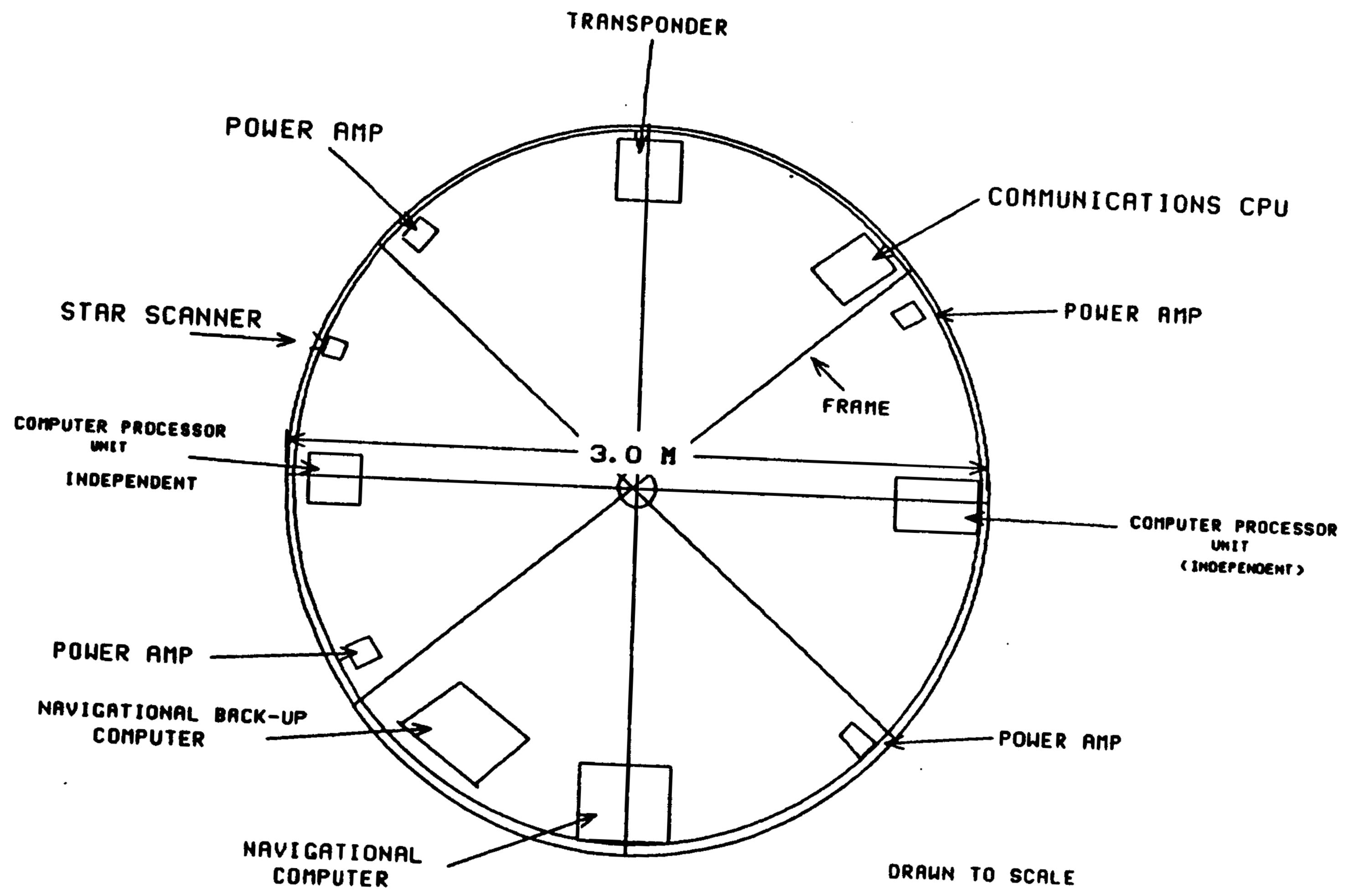


FIGURE 14: ORBITER INSTRUMENT SECTION 1

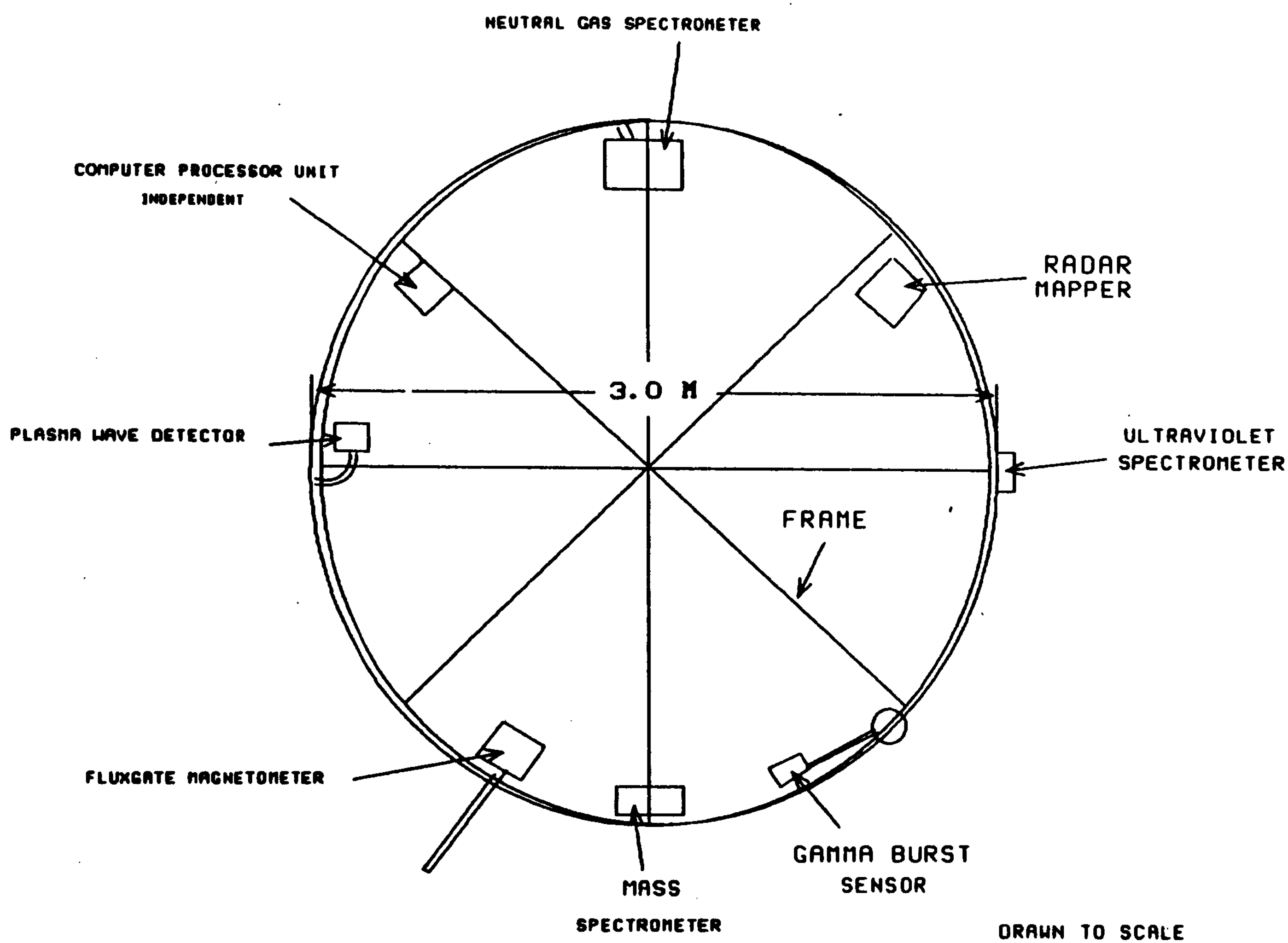
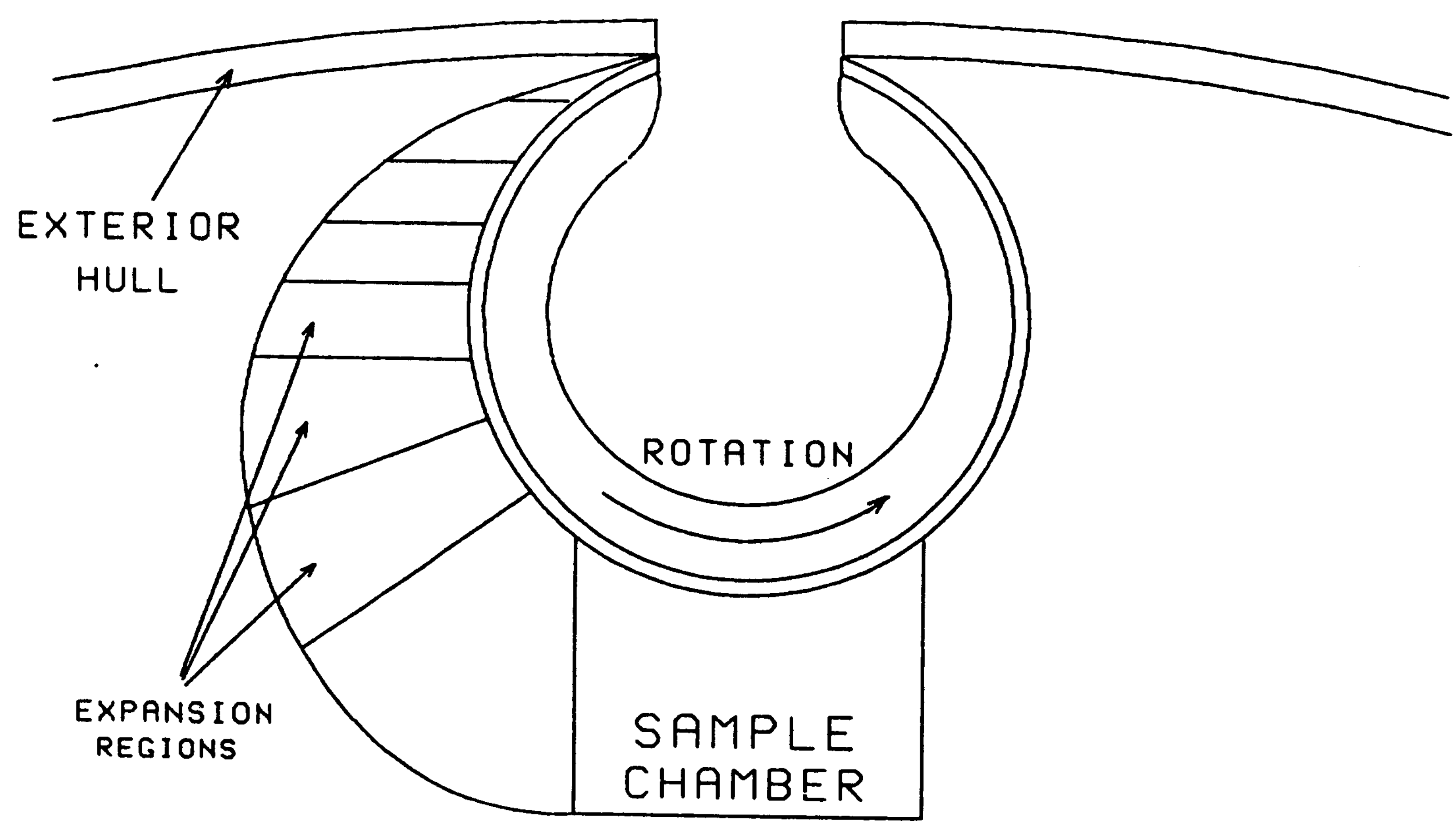


FIGURE 15: ORBITER INSTRUMENT SECTION 2



NOTE: NOT DRAWN TO SCALE

FIGURE 16: ROTATING AIRLOCK MECHANISM